Urban Climatic Mapping in Hong Kong

Towards mitigating urban heat islands in sub-tropical cities

Edward Ng and Chao Ren,*
School of Architecture, Chinese University of Hong Kong

Lutz Katzschner,
Department of Architecture, Kassel University

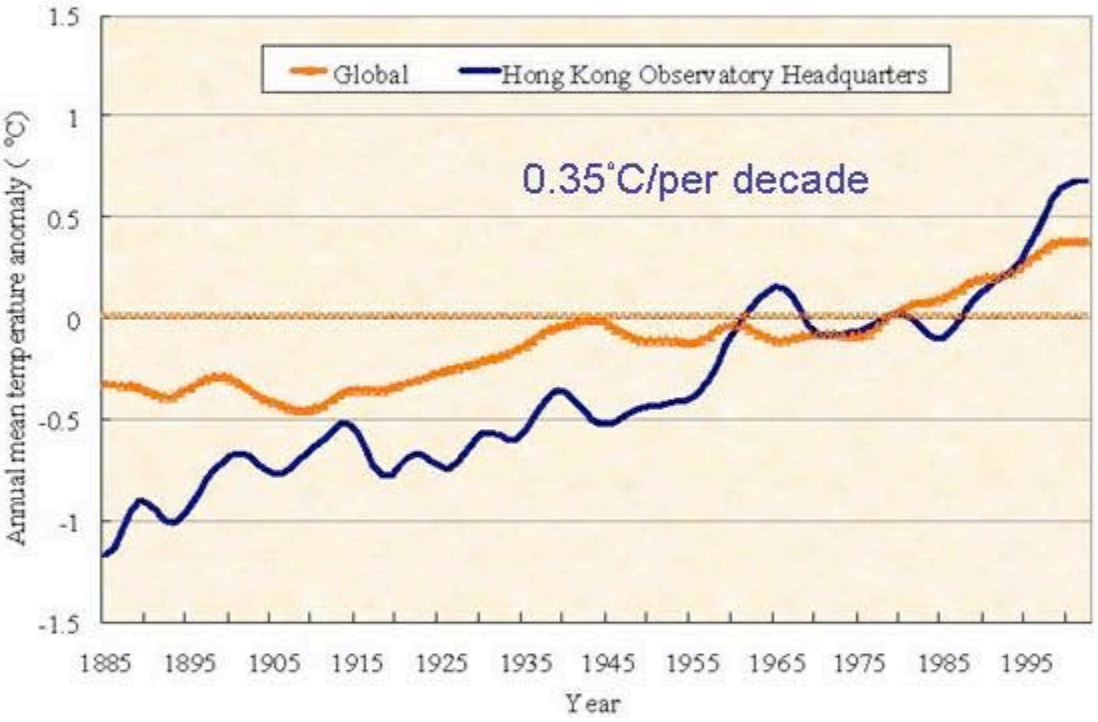
2nd International Conference on Countermeasures to Urban Heat Islands, 21-23 Sept 2009 – Berkeley, California, USA

Hong Kong – The land & its people

Land area:	1000 sq.km
Urban area:	220 sq.km
Population:	7 million
Urban density	approximately 100,000 / sq.km in metro areas

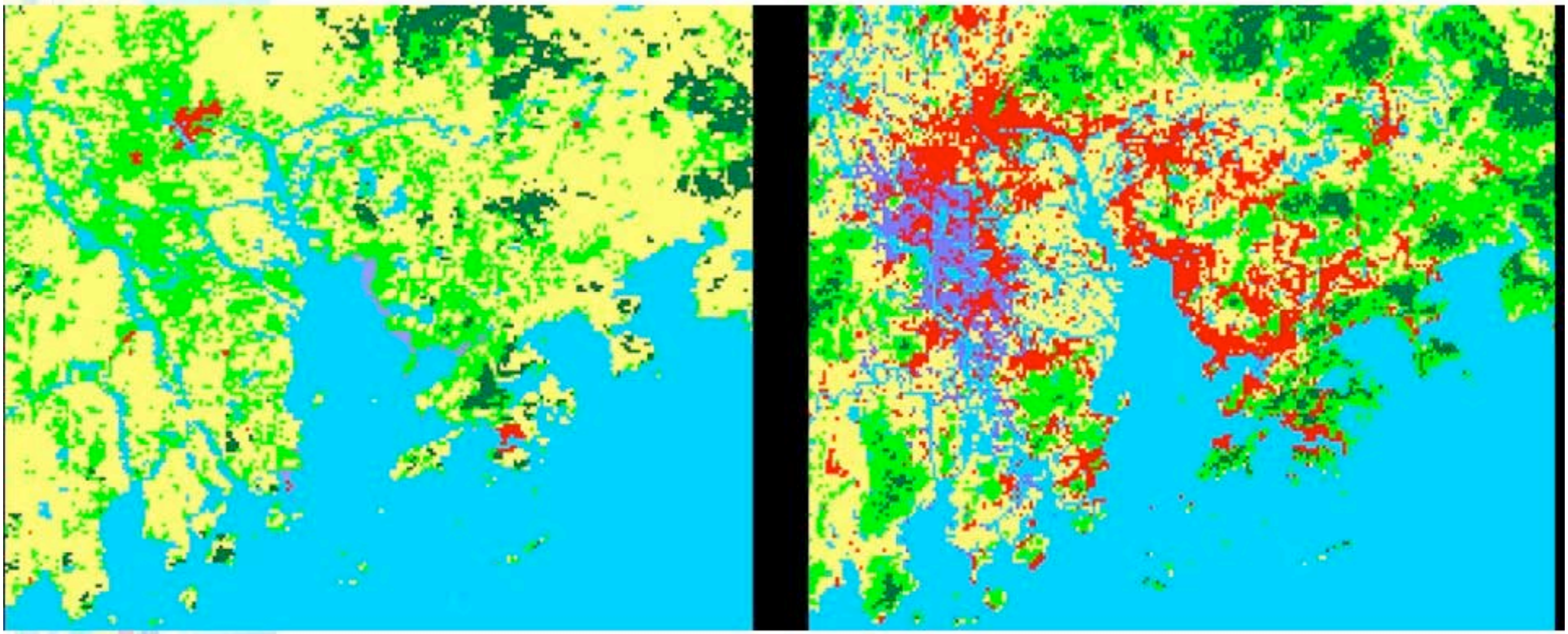
Hong Kong – The Challenges

Global and Urban Temperatures continually increasing

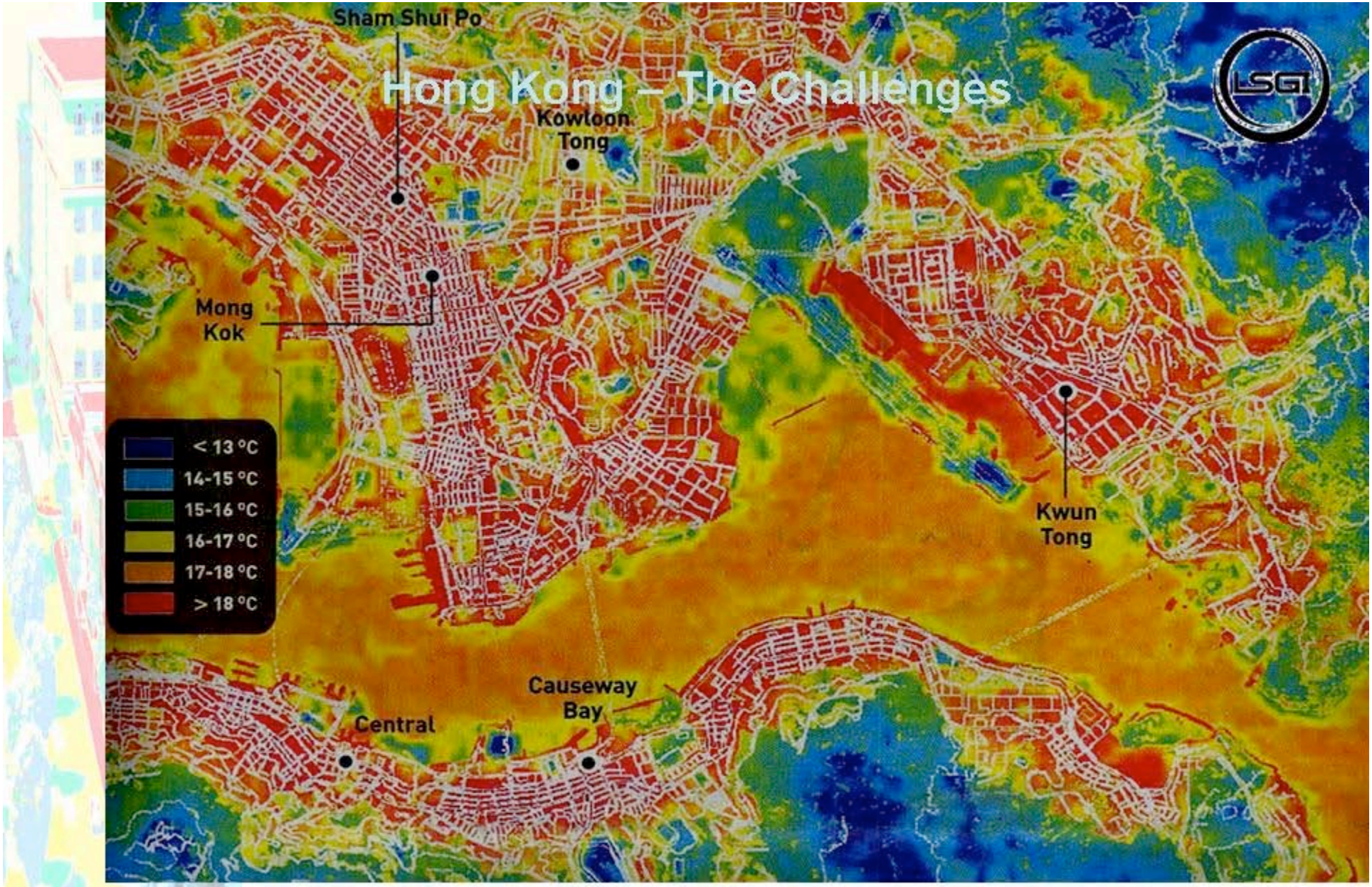


Annual mean temperature anomalies globally and at the Hong Kong Observatory Headquarters, (*Leung, Y. K., et al. (2004). Climate Change in Hong Kong. Technical Note No. 107, Hong Kong Observatory, HKSAR.*)

Fast Urbanization in the Pearl River Delta



Land cover changes in Pearl River Delta from early 1990s to 2003, Red is urbanized / sealed areas. (**Courtesy Professor Jimmy Fung, HKUST**)



Predicted air temperature, winter night time (January) HK (**Courtesy Professor Janet Nicole, HKPolyU**)

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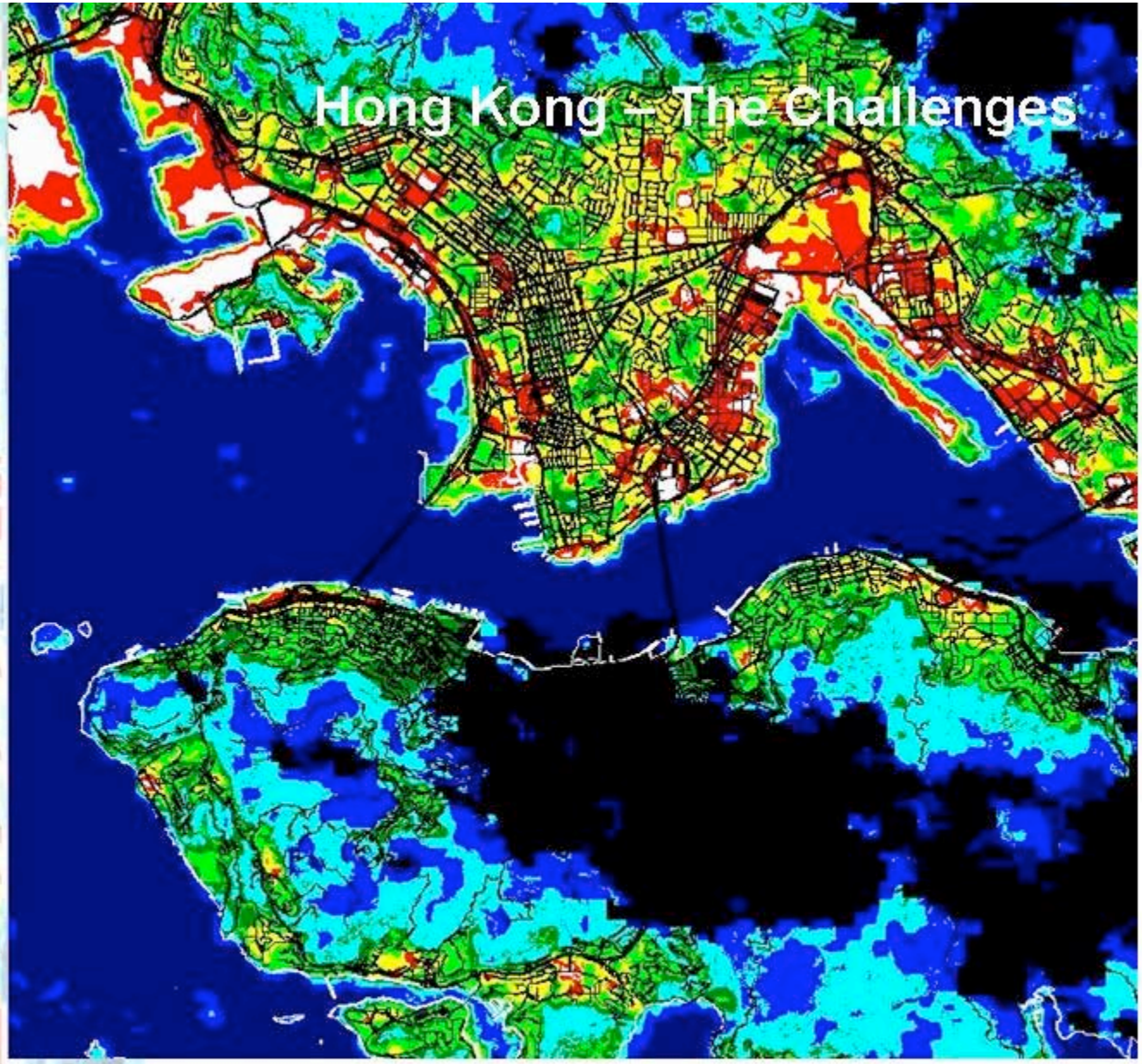
Hong Kong – The Challenges



Aug 22, 2009
Time: 11:02am

Location: Kowloon peninsula and Hong Kong island

- <=29
- 29.1-30
- 30.1-31
- 31.1-32
- 32.1-33
- 33.1-34
- 34.1-35
- >35

Predicted air temperature, summer daytime (January) HK (**Courtesy Professor Janet Nicole, HKPolyU**)

Hong Kong – Studies and Policies

中華人民共和國香港特別行政區政府
The Government of the Hong Kong Special Administrative Region of the People's Republic of China

香港政府規劃署Planning Department

技術通告 空氣流通評估方法技術指南

房屋及規劃地政局 + 環境運輸及工務局

HOUSING, PLANNING AND LANDS BUREAU TECHNICAL CIRCULAR NO. 1/06 ENVIRONMENT, TRANSPORT AND WORKS BUREAU TECHNICAL CIRCULAR NO. 1/06

HONG KONG PLANNING STANDARDS AND GUIDELINES

11章 城市設計指引

Ch11 Urban Design Guidelines

11.空氣流通意向指引

11. Qualitative Guidelines on Air Ventilation

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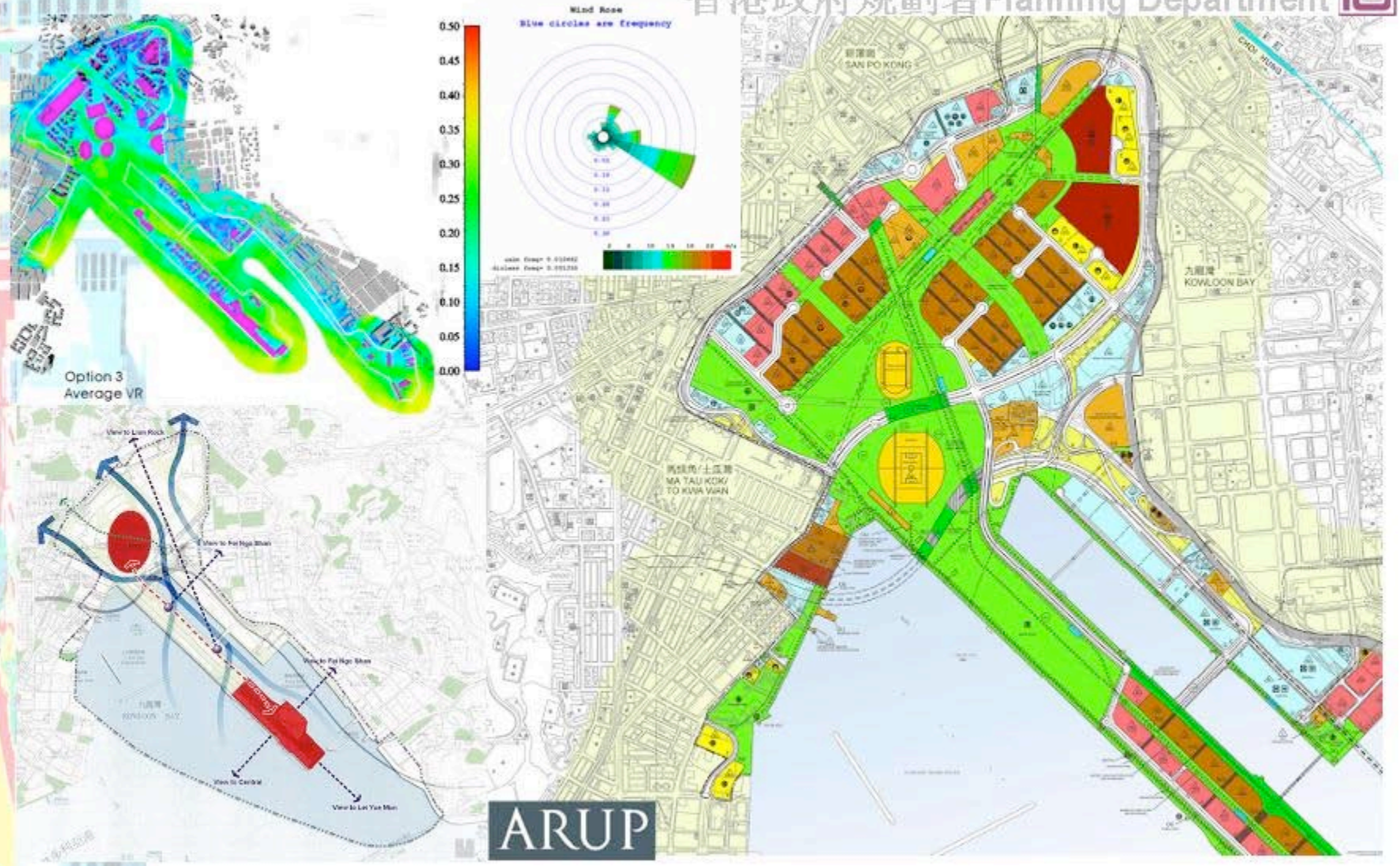
Hong Kong – A planning example

香港政府規劃署Planning Department



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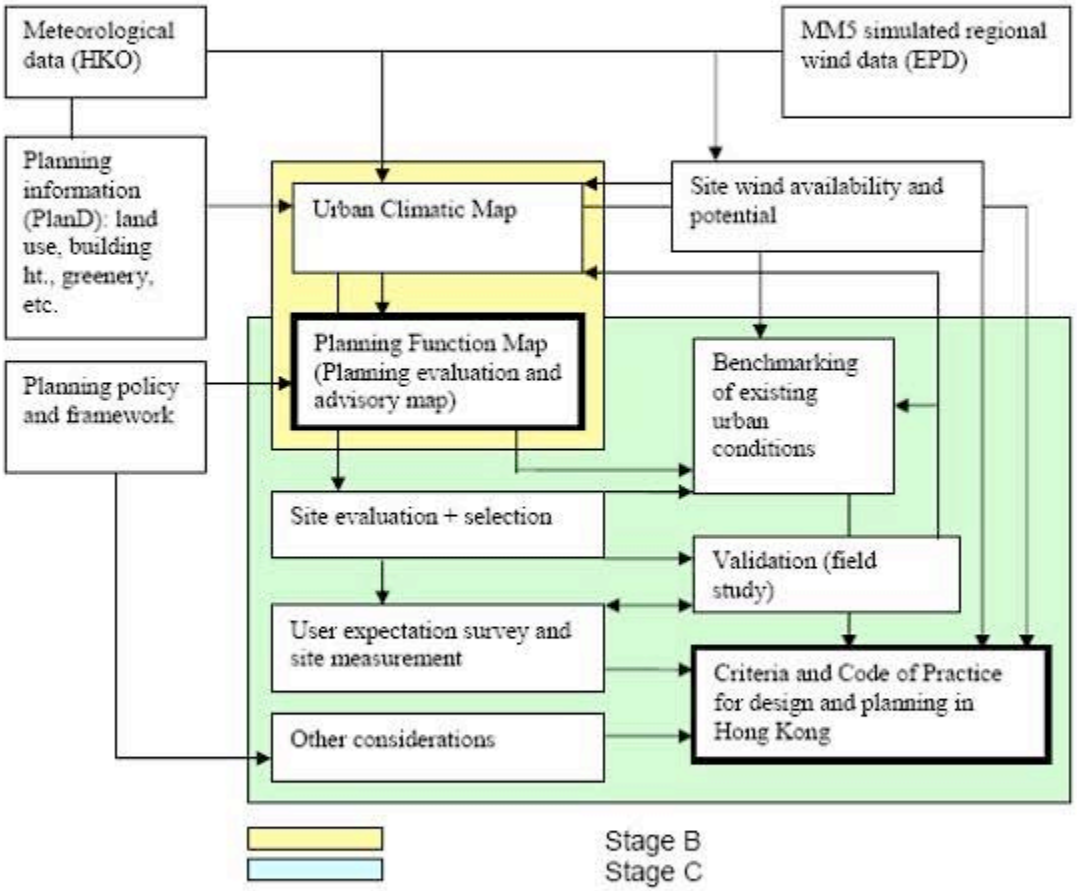
The Hong Kong Urban Climatic Map

For bio-meteorology and urban human thermal comfort esp. in the summer months



香港科技大學 THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

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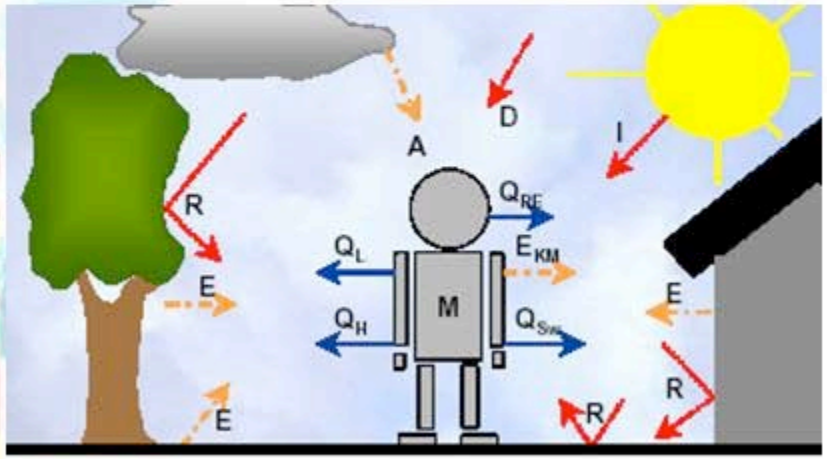
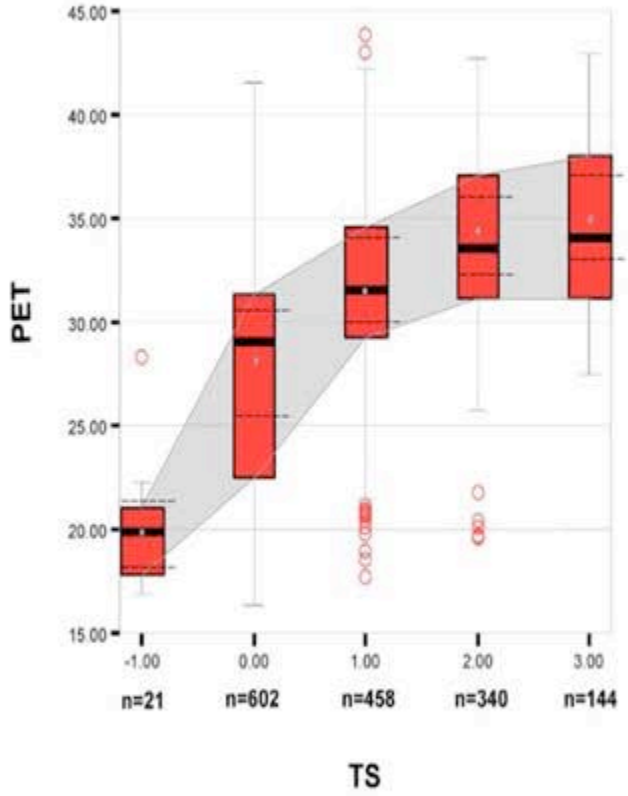
ARUP

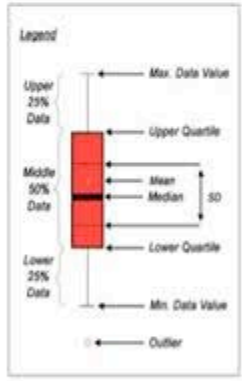
Establish neutral PET

Step 1 – what people needs as a basis of the Urban Climatic Map calibration

The "neutral" Physiological Equivalent Temperature (nPET)* of people in Hong Kong under the typical **summer condition** is in the range of **27°C to 29°C**, representing the thermal condition at which people are likely to be thermally comfortable.



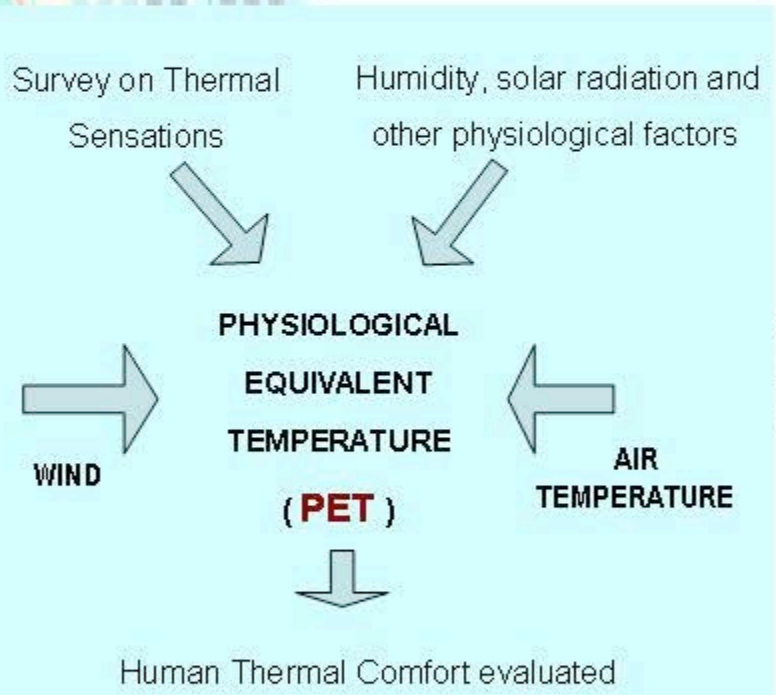


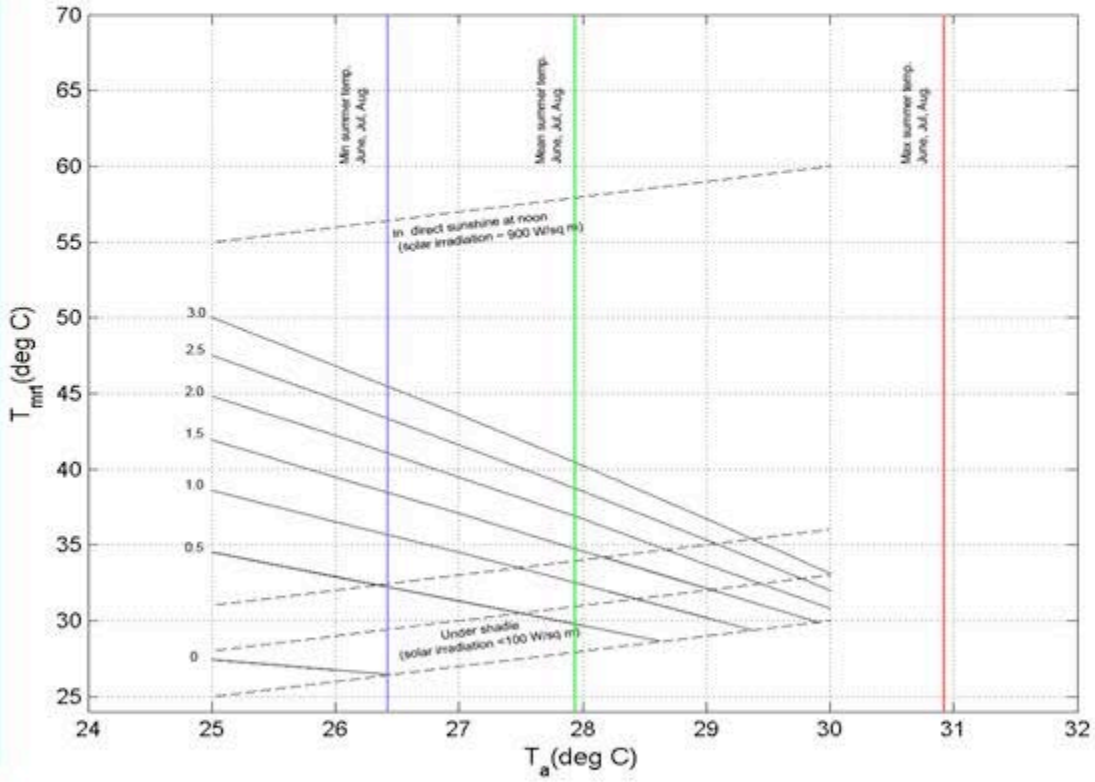


* The neutral Physiological Equivalent Temperature is the PET value that one feels neither cool nor warm when asked in the user survey.

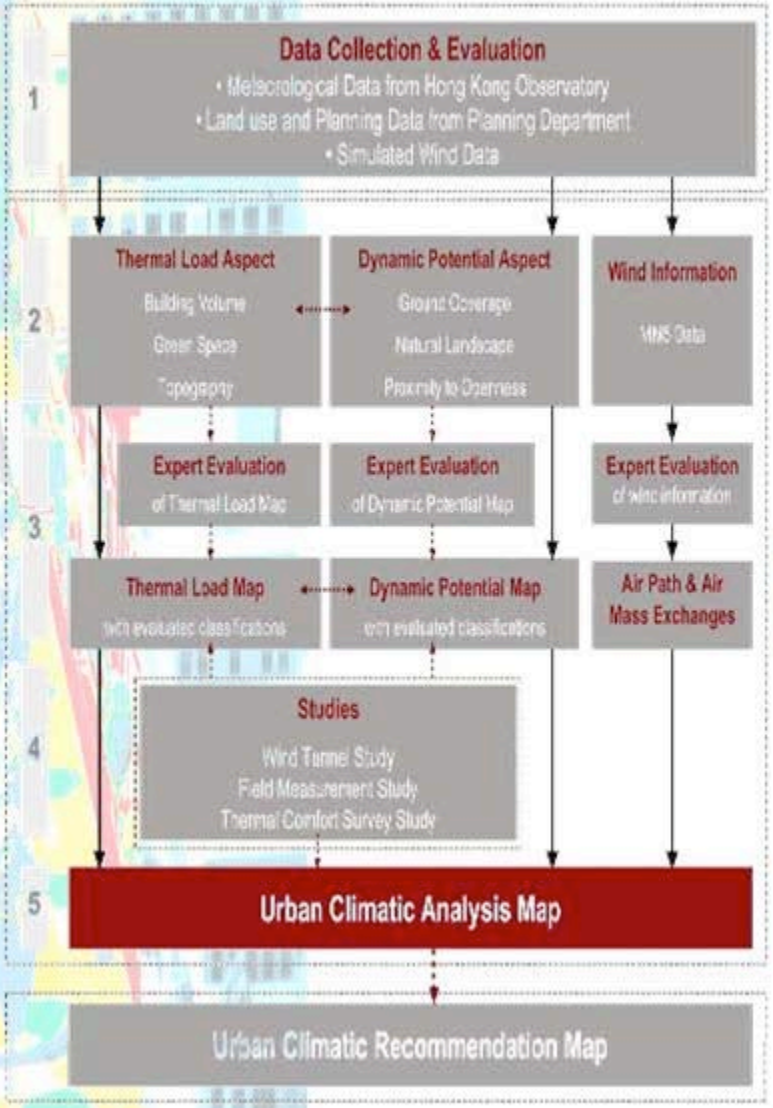
The environmental conditions of nPET

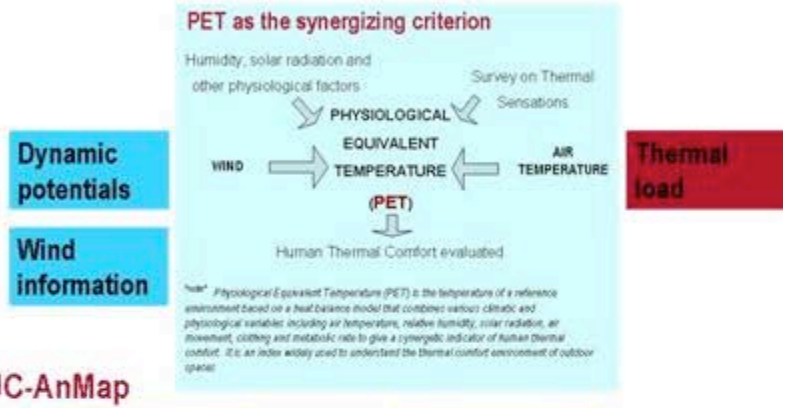
Step 2 – correlate the environmental conditions of human urban thermal comfort – air temperature, RH, Tmrt and wind.

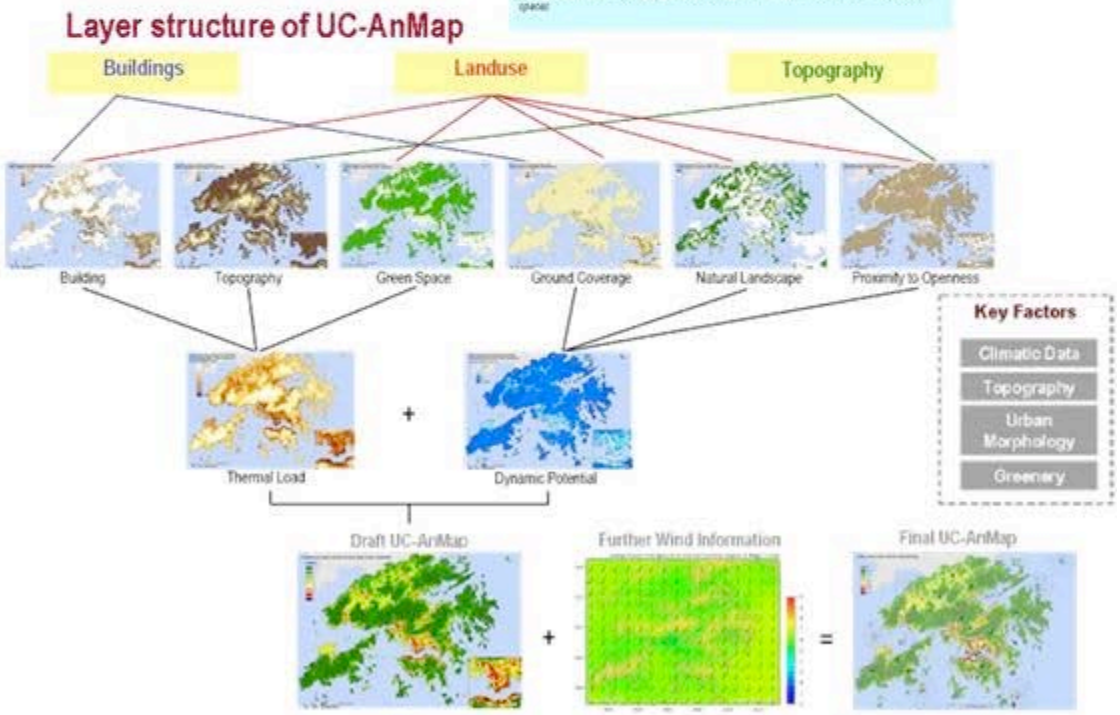




Structure and layers of Hong Kong UC-Map







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Thermal Load and Dynamic Potentials

Physical Criterion	Effect	Scientific Basis	Input layers
Thermal Load	Negative	Building bulk	Layer 1 Building Volume Map
	Positive	Altitude and Elevation	Layer 2 Topographical Height Map
		Bioclimatic effects	Layer 3 Urban Green Space Map
Dynamic Potentials	Negative	Urban permeability	Layer 4 Ground Coverage Map
	Positive	Bioclimatic effects - Cool air movement	Layer 5 Natural Landscape Map
		Air mass exchange and Neighbourhood effects	Layer 6 Proximity to Openness Map
Wind Information	Air Paths	MM5 simulation HKO wind data evaluation	Layer 7a Prevailing wind directions (summer)
			Layer 7b Prevailing wind directions (annual)

Thermal Load and Dynamic Potentials

Thermal Load:

Building Volume (Layer 1)

The building volume data are measured in cubic metres and converted to percentages of the highest building volumes in the Territory. High building volume traps solar radiation and reduces air flows. It does not just store more solar heat, but also reduces sky exposure slowing the release of solar heat at night. As a result, high building volume contributes to a significant increase in thermal load.

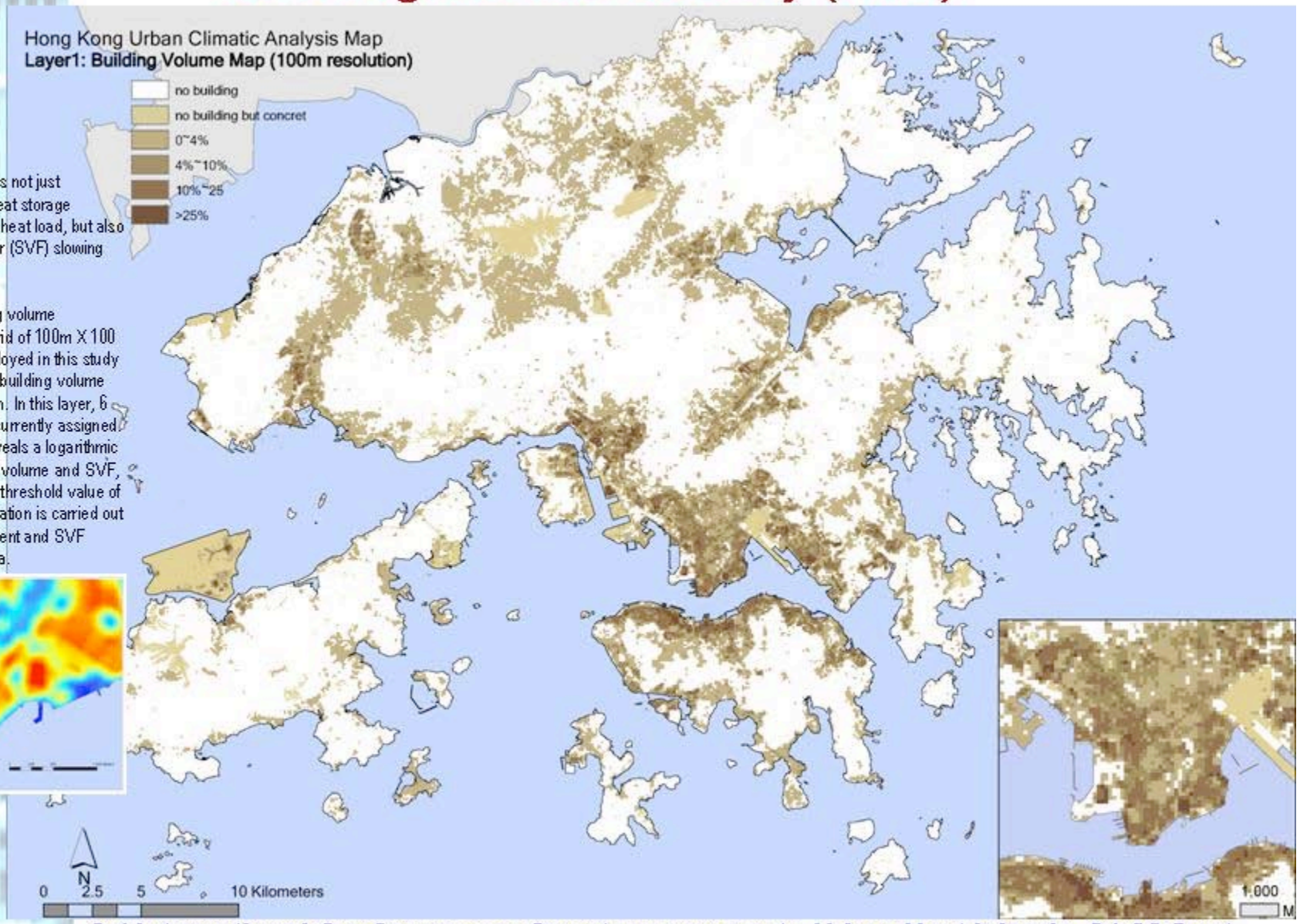
Topography (Layer 2)

The topography data are measured in metres above Principal Datum according to the Digital Elevation Model of the Planning Department. Air temperature is lower at higher altitude due to adiabatic cooling (cooling due to pressure changes). Thermal load effect is less severe in areas of higher topographical height. As Hong Kong is a hilly city, topographical condition is therefore an important factor when assessing thermal load.

Green Space (Layer 3)

Greenery has a cooling and shading effect and can reduce the surrounding air temperature. Therefore, the extent and distribution of greenery are important in affecting the thermal load. Two different classification values are assigned to urban and rural areas with or without greenery.

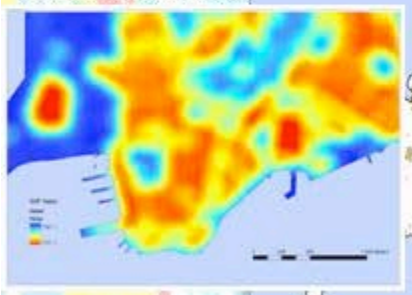
Building Volume Density (BVD)



Methodology

High building volume does not just increases the localized heat storage capacity, hence increase heat load, but also reduce the sky view factor (SVF) slowing the city's cooling at night.

Layer1 stores the building volume information within each grid of 100m X 100 m resolution. SVF is employed in this study as a medium to correlate building volume and temperature elevation. In this layer, 6 classification values are currently assigned. Our parametric model reveals a logarithmic relation between building volume and SVF, which forms the basis for threshold value of the classification. A calibration is carried out based on field measurement and SVF simulation of the TST area.



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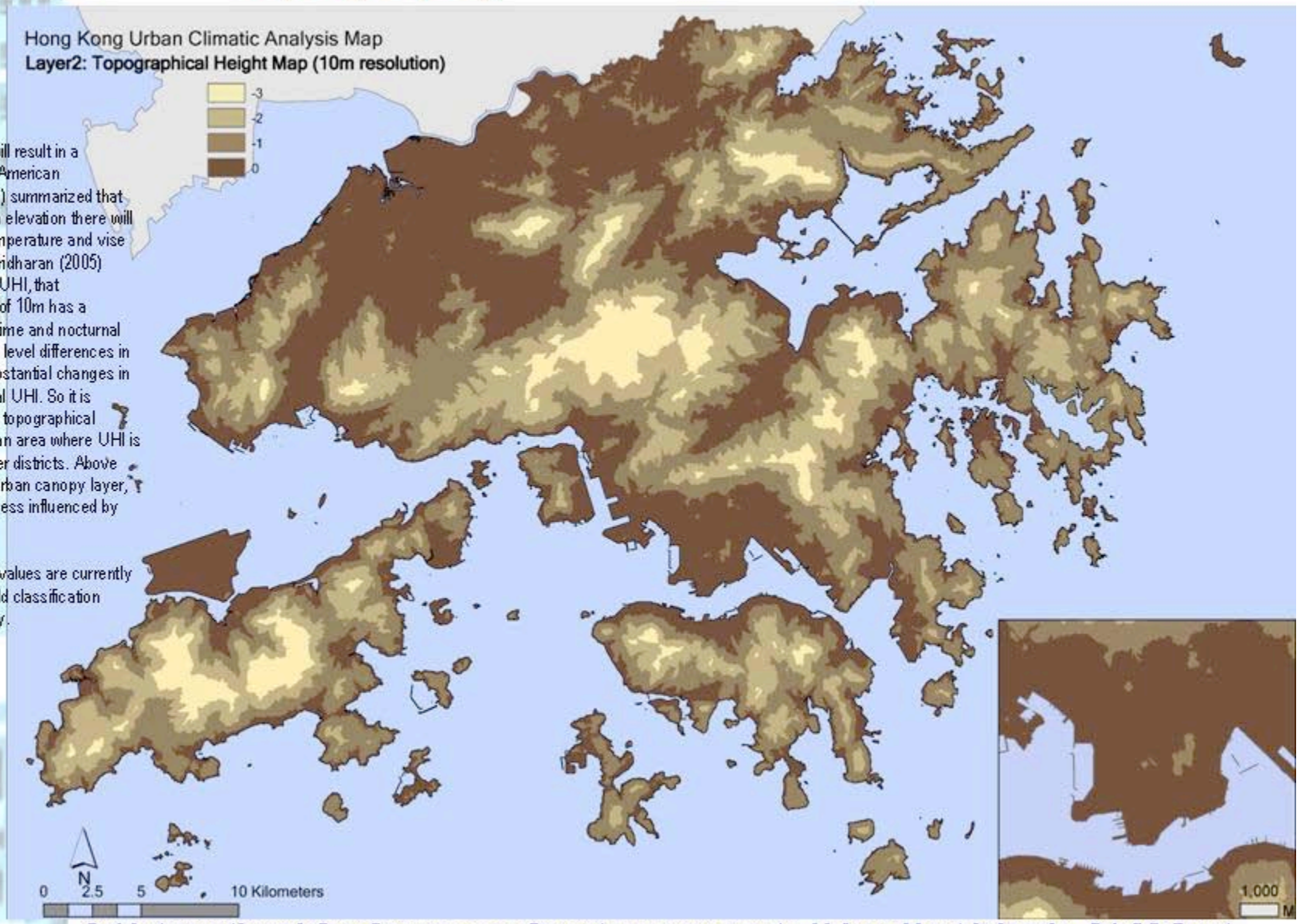
Topography

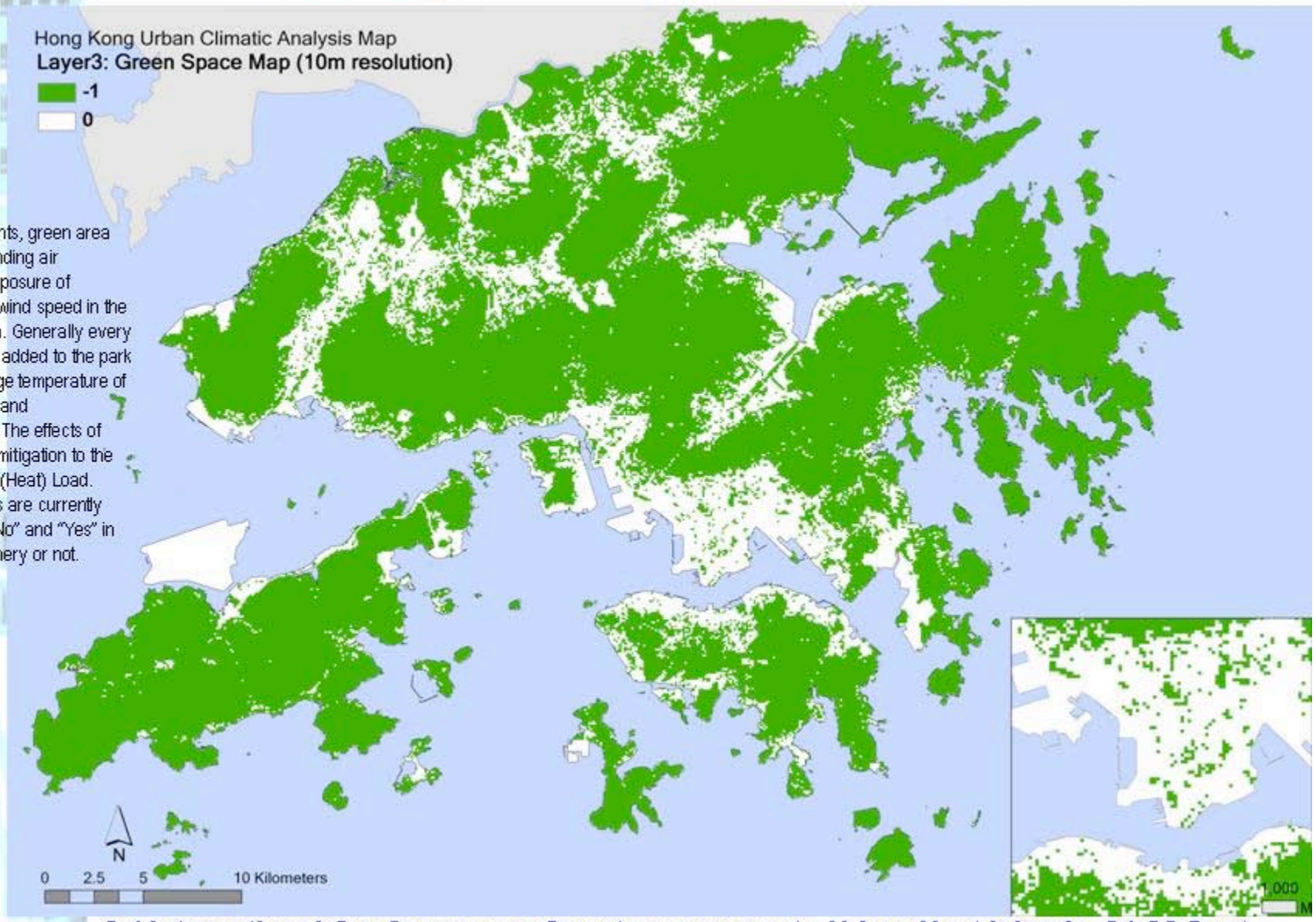


Methodology

An increase in elevation will result in a reduction in temperature. American professional Golany (1996) summarized that for every 100m increase in elevation there will be a 1° C decrease in temperature and vise versa. Local researcher Gridharan (2005) concluded for Hong Kong UHI, that topography up to a height of 10m has a marginal influence on daytime and nocturnal UHI. Beyond 10m altitude, level differences in topography will reduce substantial changes in both daytime and nocturnal UHI. So it is reasonable to group those topographical heights less than 10m as an area where UHI is more significant than higher districts. Above 200m – 300m, which the urban canopy layer, the wind profile will be far less influenced by the urban structures.

In Layer2, 4 classification values are currently assigned, and the threshold classification value is not chosen linearly.

Greenery

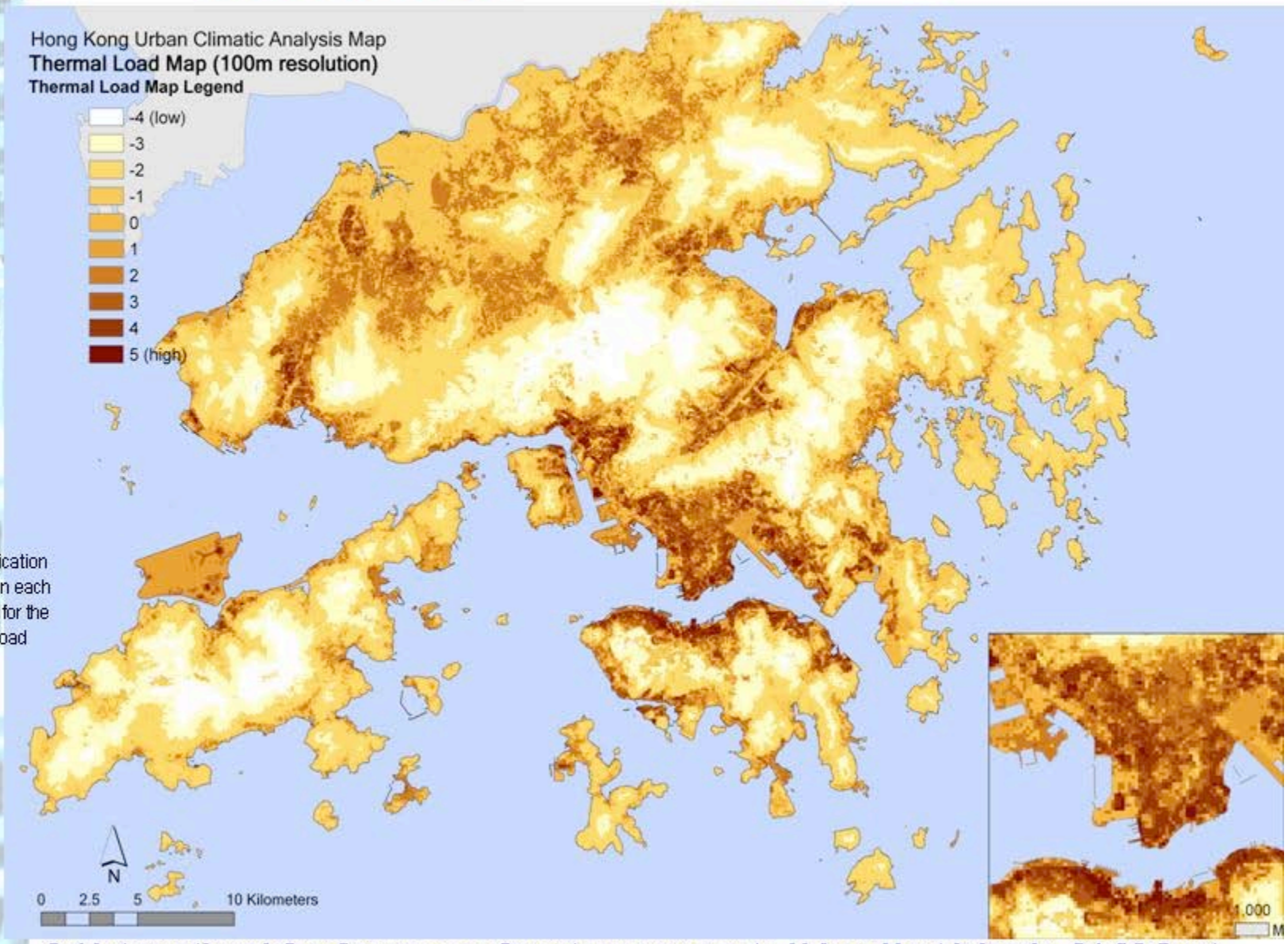


Methodology

For urban environments, green area can affect the surrounding air temperature, solar exposure of pedestrians, and the wind speed in the streets (Givoni, 1998). Generally every 100 m2 of vegetation added to the park can reduce an average temperature of around 1 K (Dimoudi and Nikolopoulou, 2003). The effects of green areas provide mitigation to the undesirable Thermal (Heat) Load. 2 classification values are currently assigned, meaning "No" and "Yes" in terms of having greenery or not.

Thermal Load

By adding the specific classification values of the above 3 layers in each grid, the classification values for the composite layer of Thermal Load are derived.



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Dynamic Potentials

Dynamic Potential:
Ground Coverage (Layer 4)

Ground coverage measures the ground roughness in terms of percentages of ground occupied by buildings in a locality and indicates the urban permeability to wind. Larger ground coverage such as large podia will contribute to a reduction in pedestrian wind speed. Therefore, the extent of ground coverage is important in affecting the dynamic potential.

Natural Landscape (Layer 5)

Natural landscape, particularly grassland, has low roughness, which possesses higher dynamic potential than other landscape types, such as, woodland and urban landscape. Thus, grassland will contribute to dynamic potential to the city. 2 classification values are currently assigned, “Grassland” and "Woodland and Urban Landscape”.

Proximity to Openness (Layer 6)

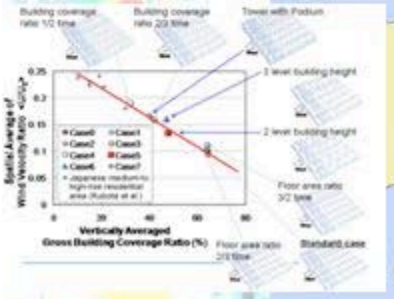
This layer consists of 3 sub-layers of 3 different parameters: proximity to waterfront, proximity to open space and slope with vegetation. Waterfront, open areas and vegetated slopes are sources of air ventilation, and the locations of building developments in close proximity in relation to these features can benefit from them. For example, sea breezes decrease as the distances to sea shore increase. Distances in metres to waterfront, open space or slopes are given different classification values to estimate their dynamic potential.

Ground cover percentage

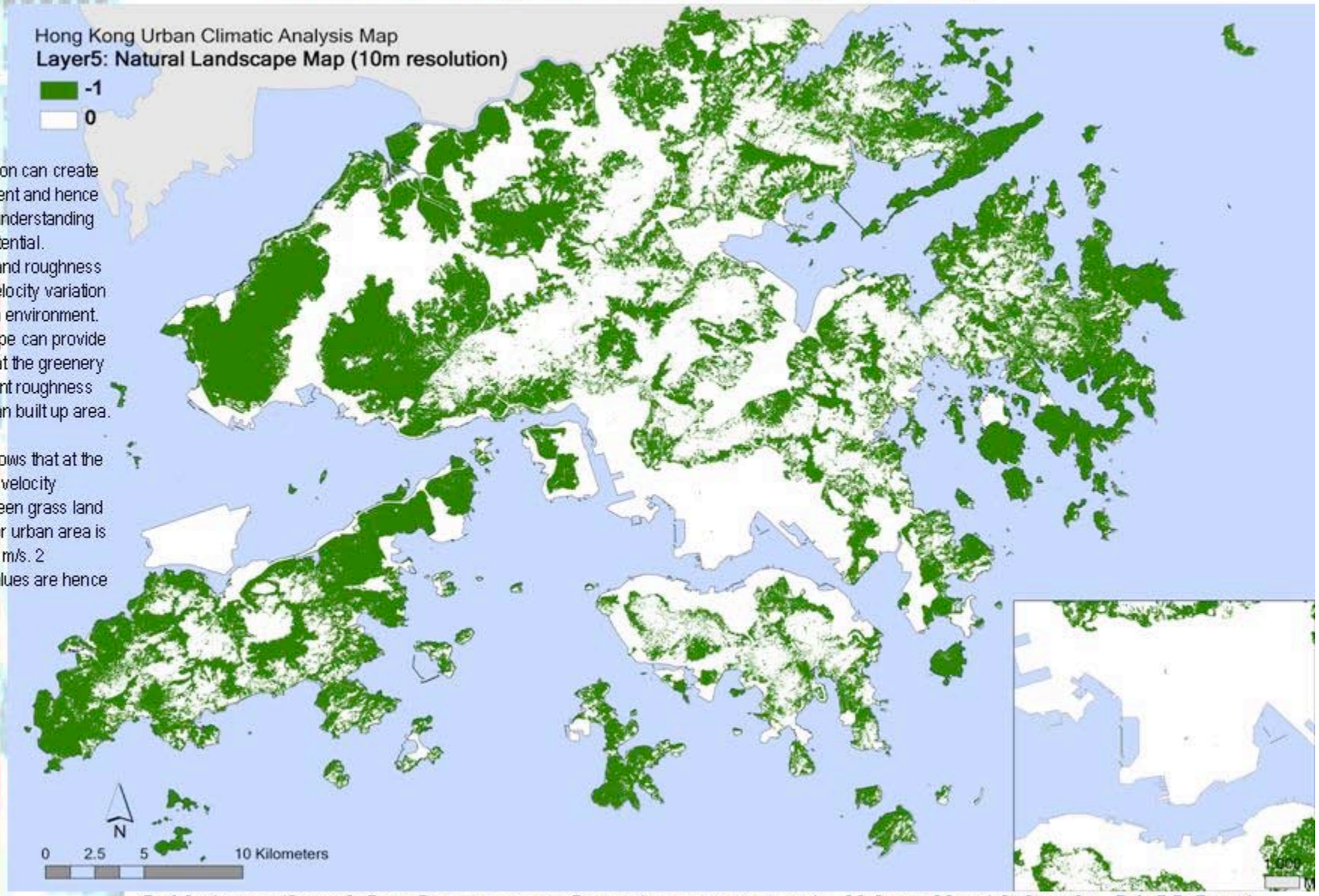
Methodology

Ventilation performance is a key consideration in building design and urban planning. Generally speaking, built-up urban structures can deflect local wind flow and block its outlets for the circulation. In Yoshie's research findings of both Japan cities and also Mong Kok in Hong Kong (2007), there is an evident trend in the relationship between gross building coverage ratio (in percentage) and wind velocity ratio. Higher wind velocity ratio is experienced where there is relatively low building coverage, which indicates the relations between urban permeability and ground coverage, and vice versa.

Layer4 synthetically combines the understanding of building coverage and ground roughness. 3 classification values are currently assigned.



Natural vegetation (roughness)



Methodology

Natural vegetation can create cool air movement and hence is important in understanding the dynamic potential. Differences in land roughness result in wind velocity variation within the urban environment. Natural landscape can provide ventilation in that the greenery area has different roughness length than urban built up area.

Our analysis shows that at the level of 2m, the velocity difference between grass land and woodland or urban area is approximately 1 m/s. 2 classification values are hence assigned.

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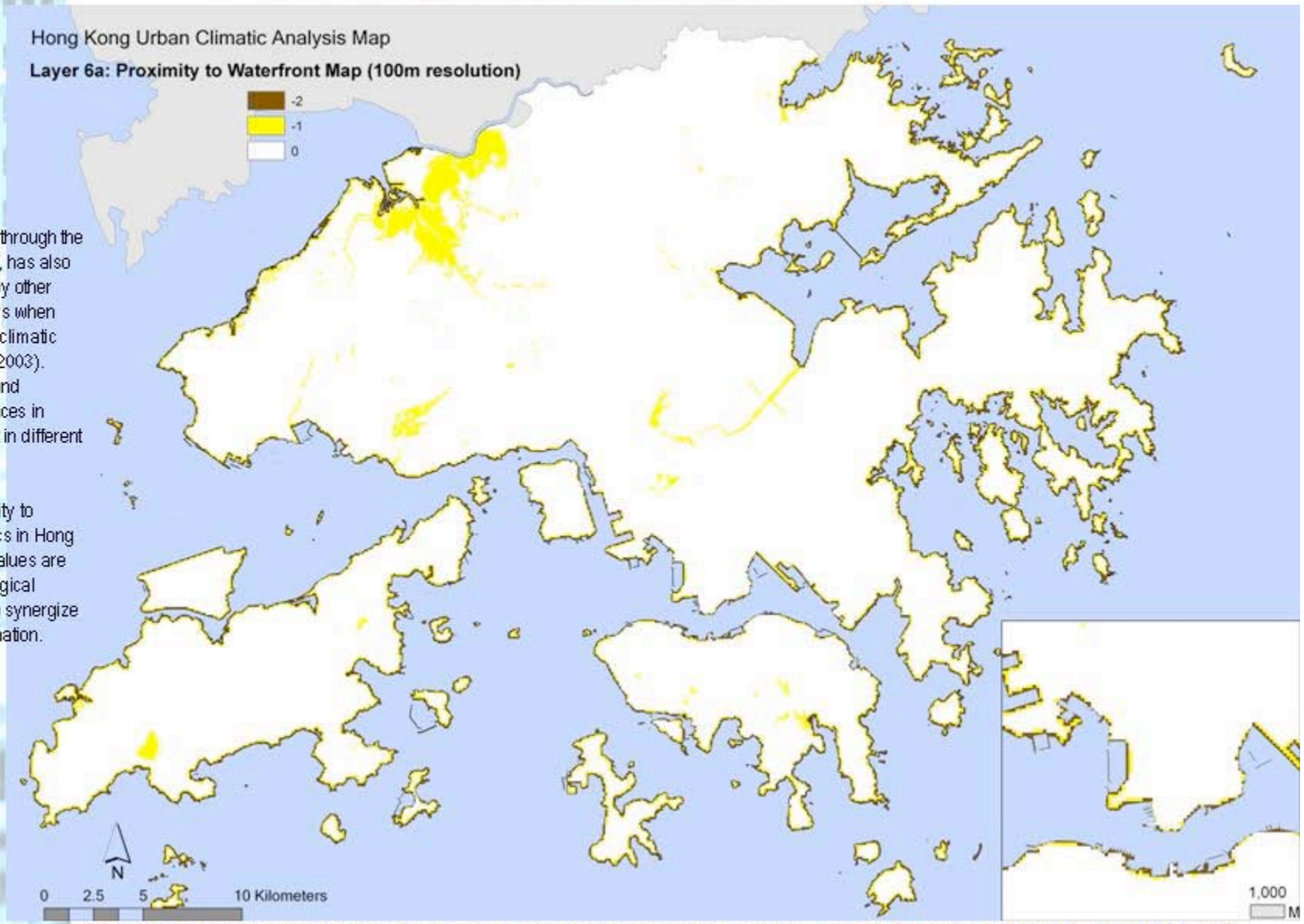
Proximity to waterfront



Methodology

Sea breeze, measured through the distance from the coast, has also been a major concern by other international researchers when they create large-scale climatic maps (Svensson et al. 2003). Similar to Layer 4-Ground Coverage Map, differences in roughness length result in different wind availability.

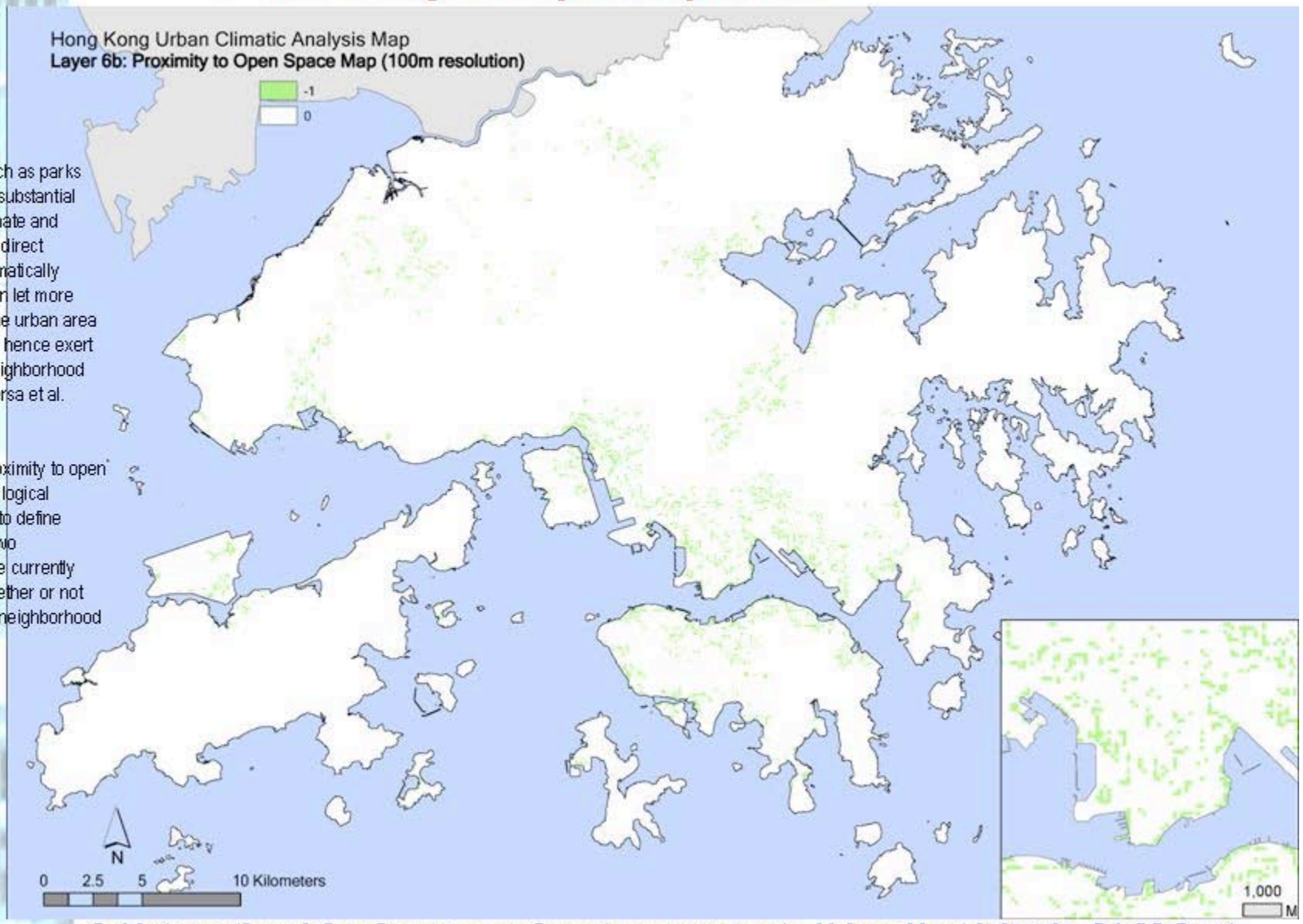
Layer 6a shows proximity to waterfront characteristics in Hong Kong. 2 classification values are currently assigned. A logical function is developed to synergize ground coverage information.

Proximity of open spaces

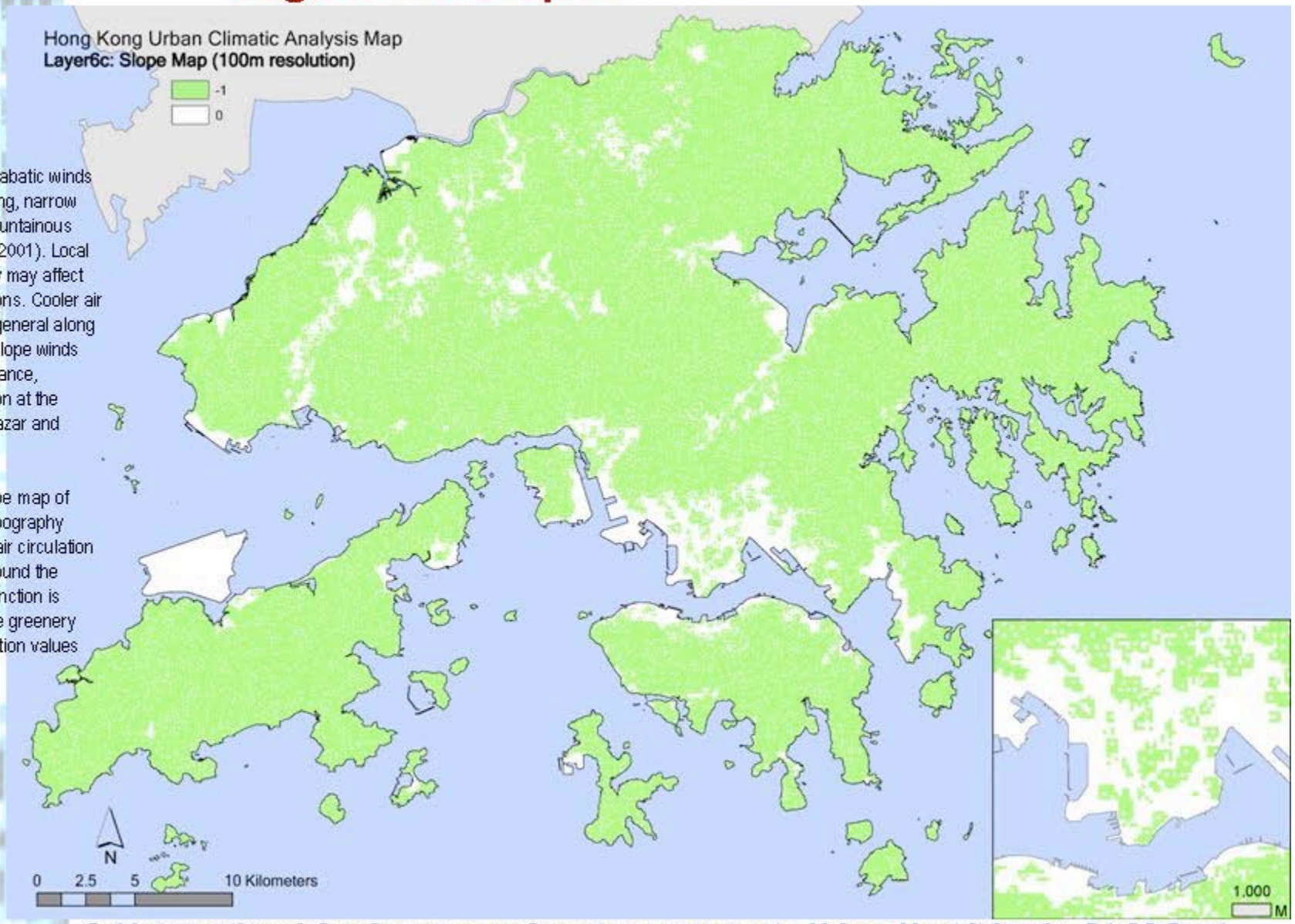
Methodology

Urban open spaces such as parks and open area have a substantial effect on the urban climate and positively influence the direct surroundings micro-climatically (Berlin, 2004). They can let more wind penetration into the urban area and create air path and hence exert cooling effects upon neighborhood area (Koomena, Dekkersa et al. 2007).

Layer 6b shows the proximity to open space in urban area. A logical function is established to define "urban open space". Two classification values are currently assigned indicating whether or not the space benefit from neighborhood open space.



Vegetated slopes

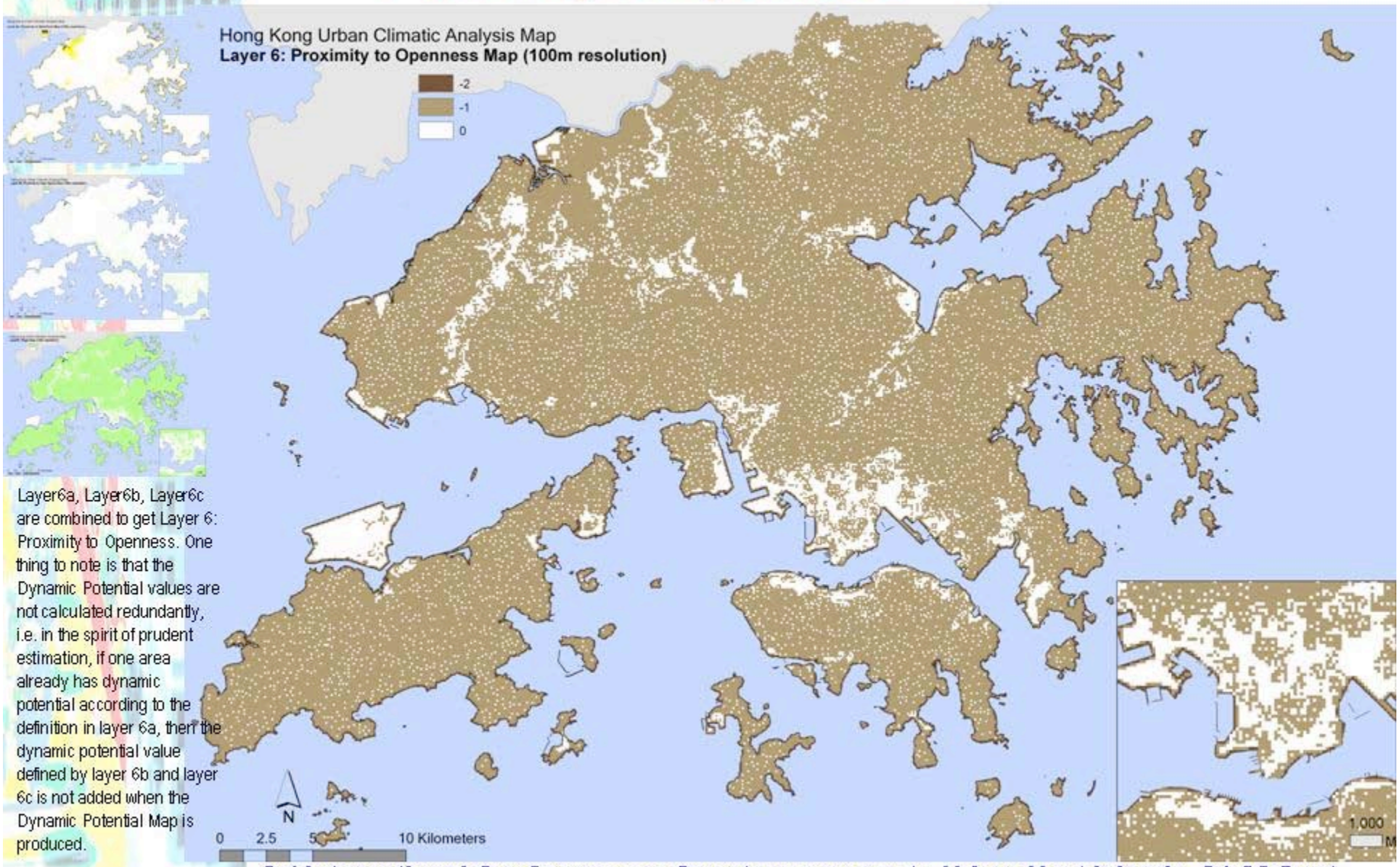


Methodology

The phenomenon of katabatic winds is frequently found in long, narrow and steep valleys in mountainous areas (Fernando et. al. 2001). Local variations in topography may affect greatly the wind conditions. Cooler air moves downhill and in general along the valleys. The down-slope winds are only of local significance, especially for the location at the bottom of the slopes (Lazar and Podesser, 1999).

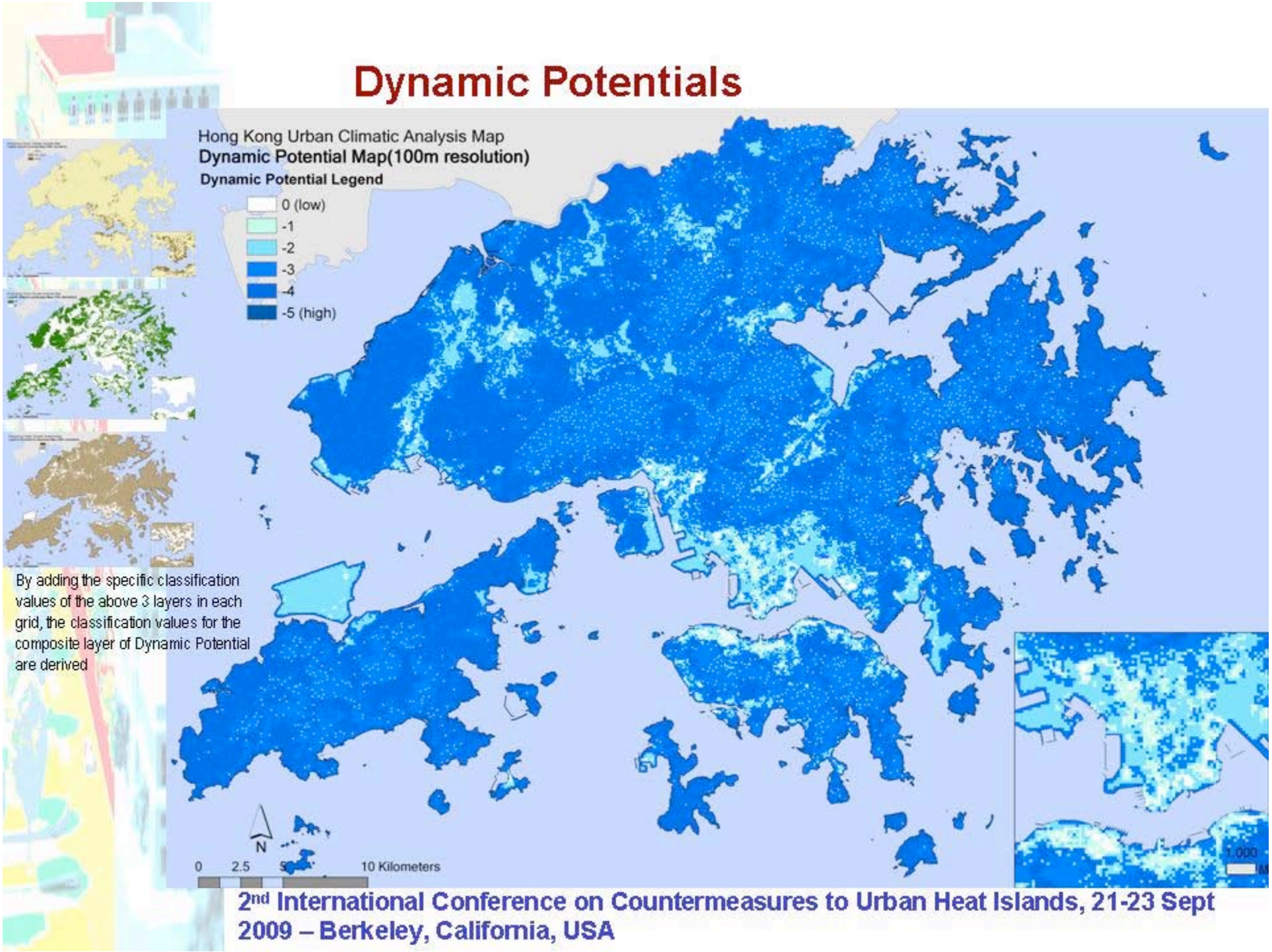
Layer 6c shows the slope map of Hong Kong. Steeper topography (>40%) will strengthen air circulation and wind movement around the topography. A logical function is established to synergize greenery information. 2 classification values are currently assigned.

Proximity to Openness



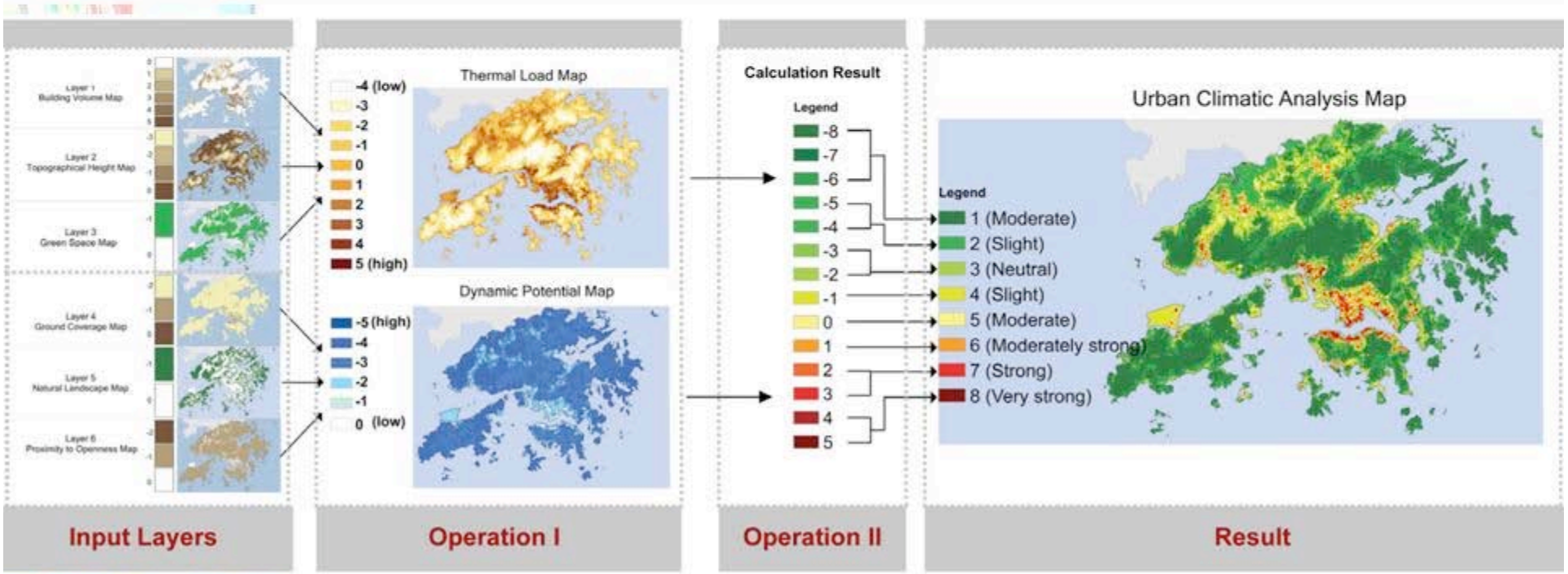
Layer6a, Layer6b, Layer6c are combined to get Layer 6: Proximity to Openness. One thing to note is that the Dynamic Potential values are not calculated redundantly, i.e. in the spirit of prudent estimation, if one area already has dynamic potential according to the definition in layer 6a, then the dynamic potential value defined by layer 6b and layer 6c is not added when the Dynamic Potential Map is produced.

Dynamic Potentials

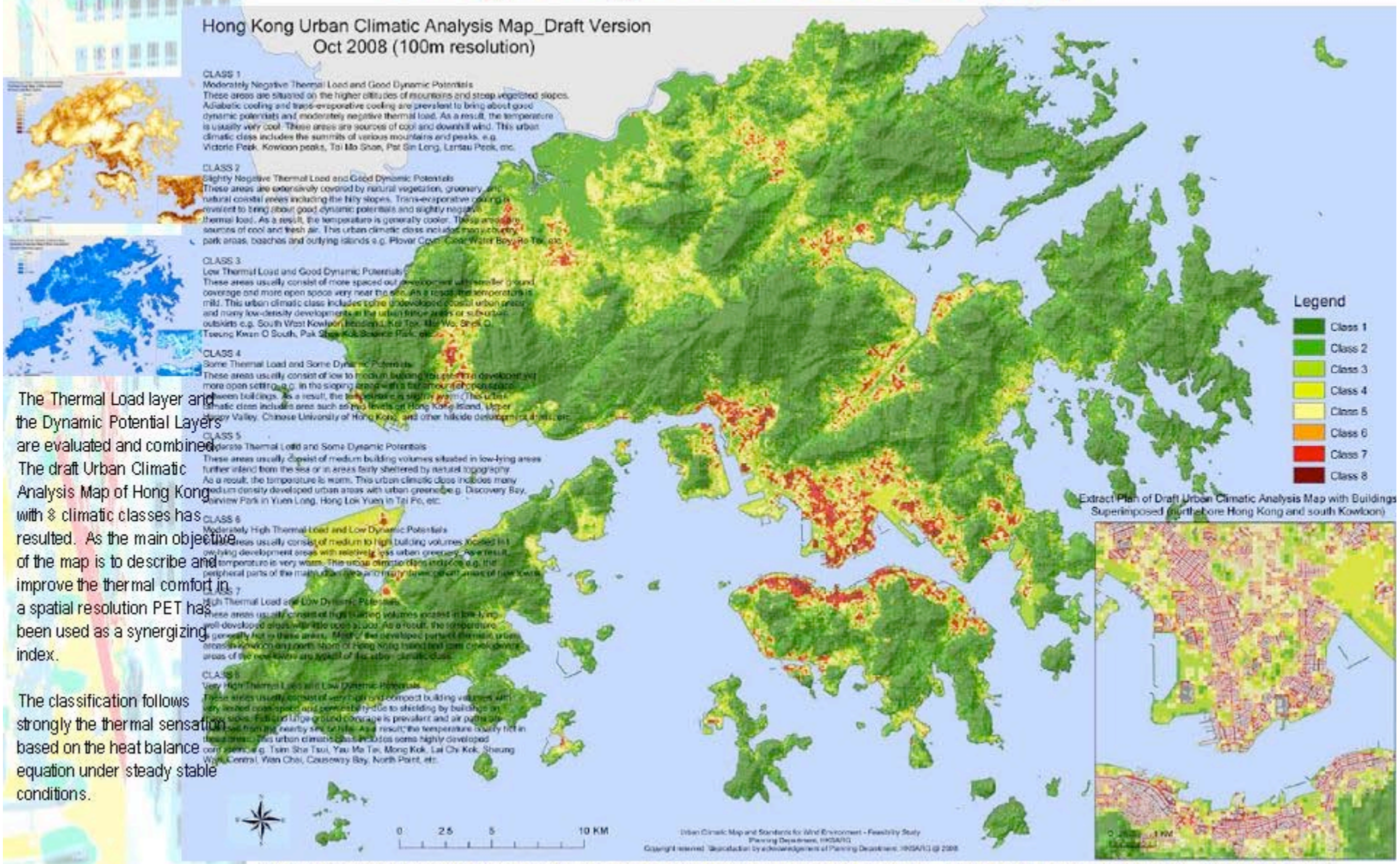


Thermal Load + Dynamic Potentials

	Urban Climatic Class	Impact on Thermal Comfort	Urban Climatic Value / Sensitivity Zone	Possible action
1	Moderately negative Thermal Load and Good Dynamic Potentials	•• Moderate	(A) Urban climatically valuable area	Preserve
2	Slightly negative Thermal Load and Good Dynamic Potentials	• Slight		
3	Low Thermal Load and Good Dynamic Potentials	- Neutral	(B) Slightly urban climatically sensitive area	Preserve & enhance
4	Some Thermal Load and Some Dynamic Potentials	• Slight		
5	Moderate Thermal Load and Some Dynamic Potentials	•• Moderate	(C) Urban climatically sensitive area	Action desirable
6	Moderately High Thermal Load and Low Dynamic Potentials	••• Moderately strong		
7	High Thermal Load and Low Dynamic Potentials	•••• Strong	(D) Highly urban climatically sensitive area	Action necessary
8	Very High Thermal Load and Low Dynamic Potentials	••••• Very strong		



Hong Kong Urban Climatic Map



The Thermal Load layer and the Dynamic Potential Layers are evaluated and combined. The draft Urban Climatic Analysis Map of Hong Kong with 8 climatic classes has resulted. As the main objective of the map is to describe and improve the thermal comfort in a spatial resolution PET has been used as a synergizing index.

The classification follows strongly the thermal sensation based on the heat balance equation under steady stable conditions.

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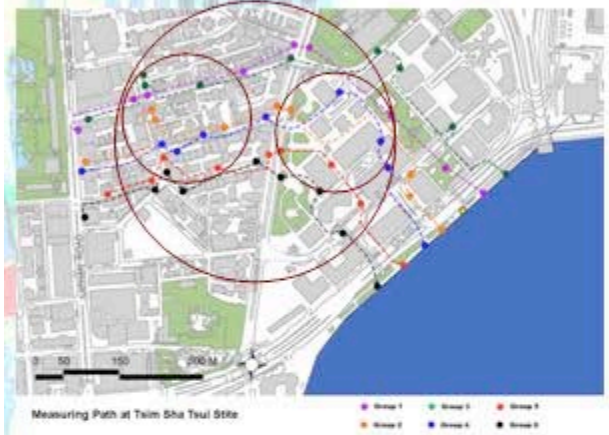
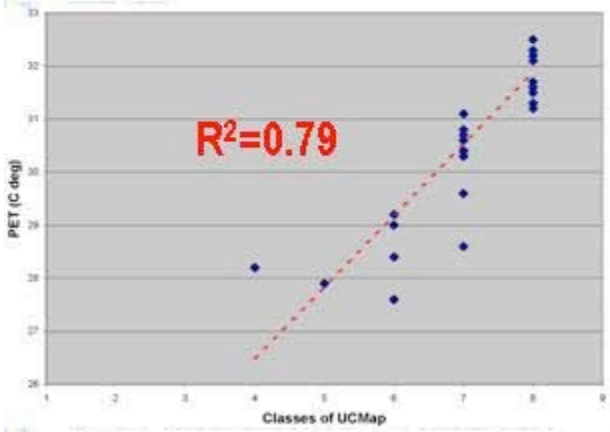
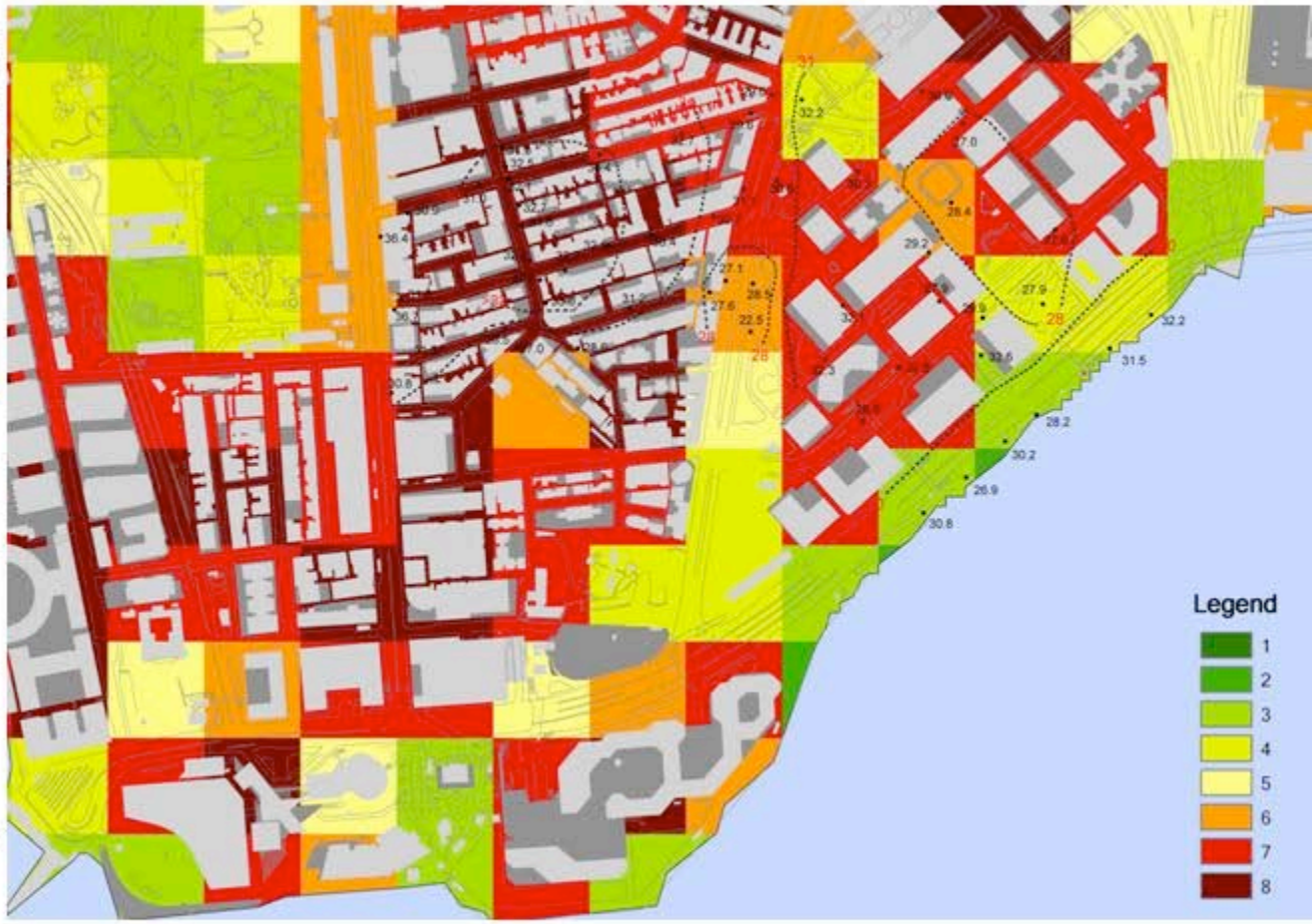
Calibration and validation I

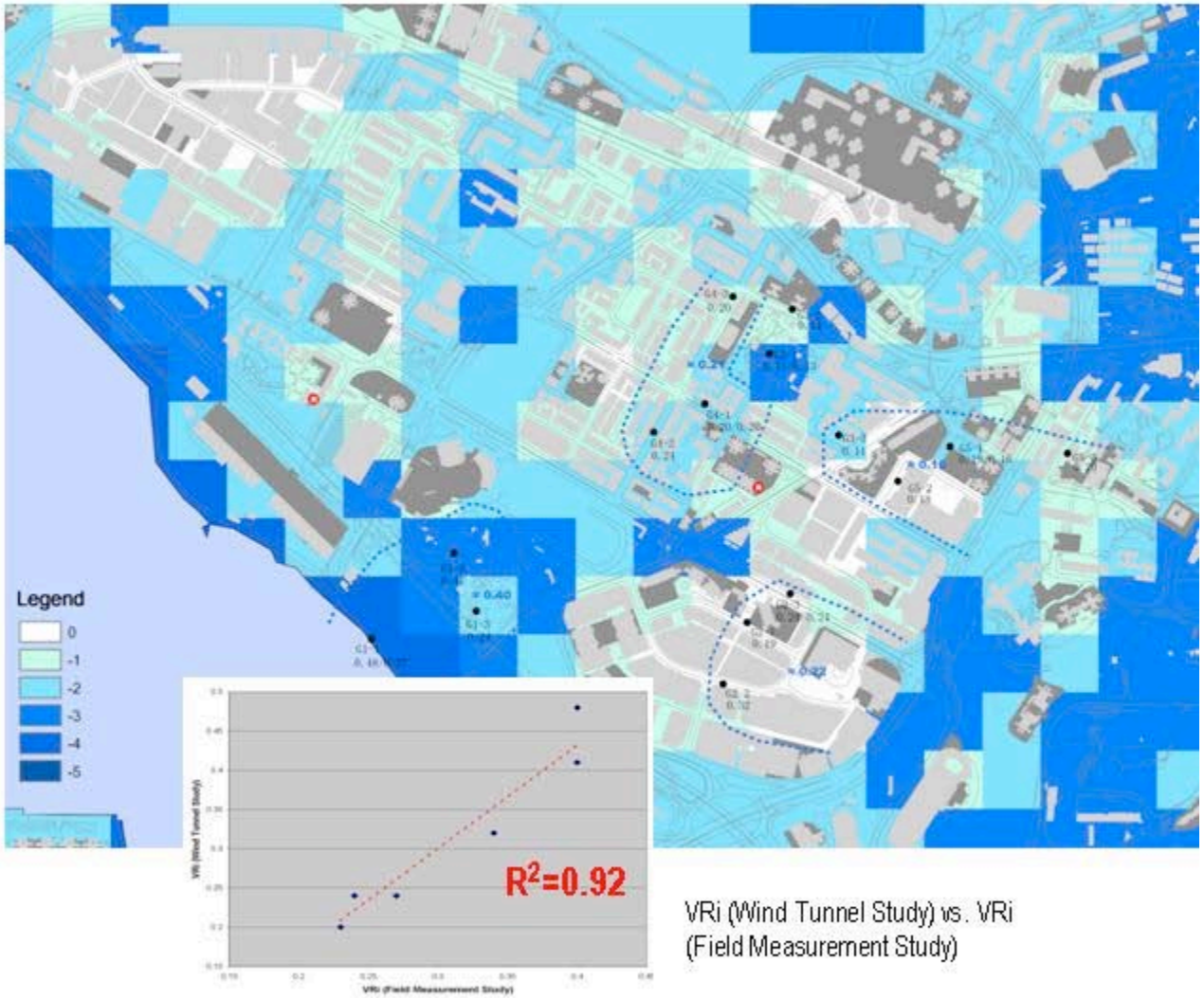




The relationship between PET and the classes of UCAn-Map based on the result of spot field measurement in TST areas.

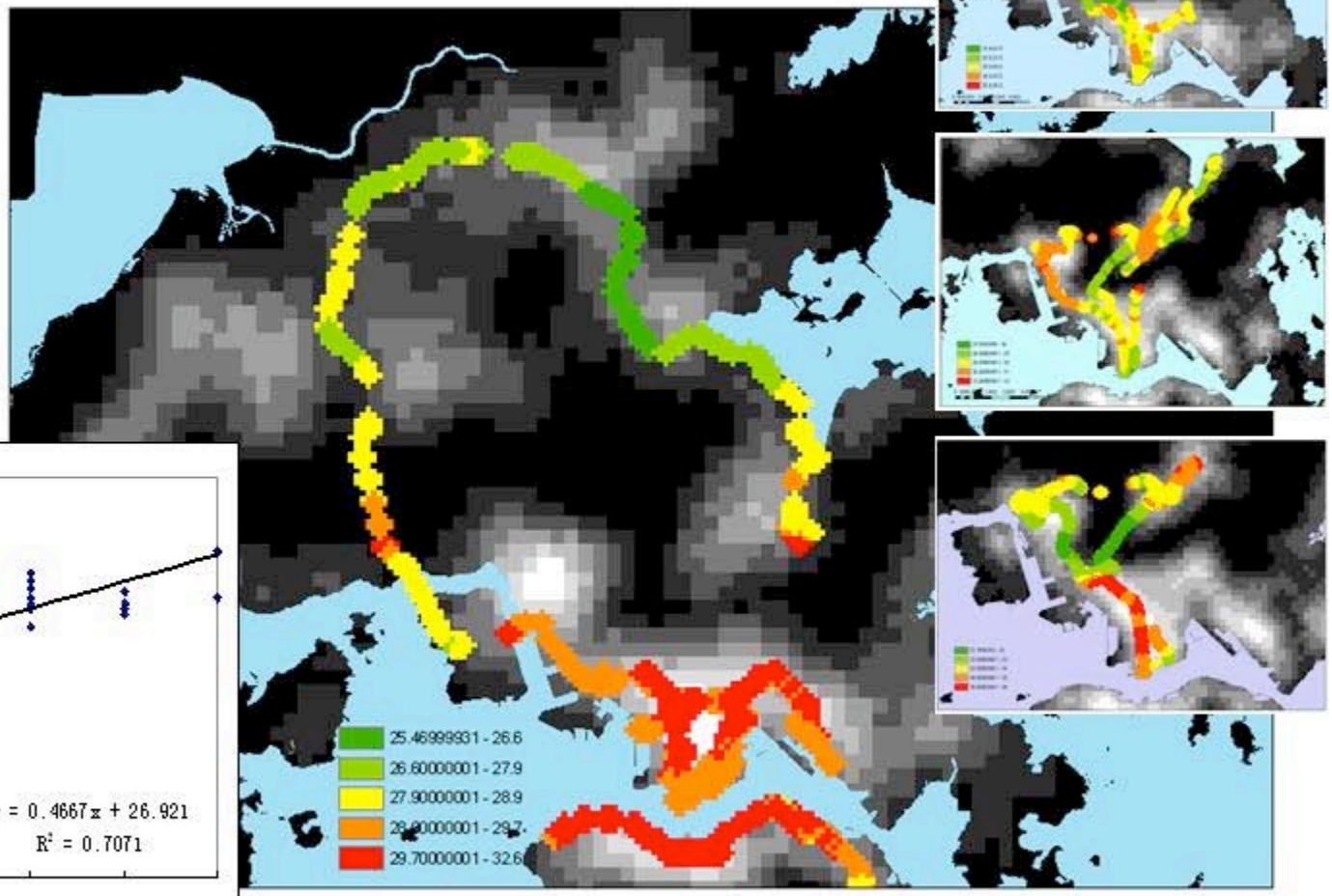


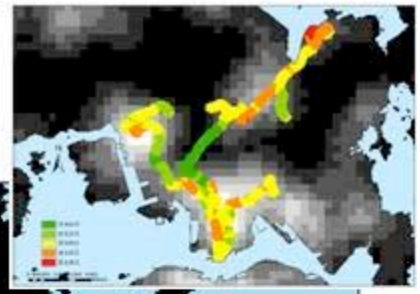
Calibration and validation II

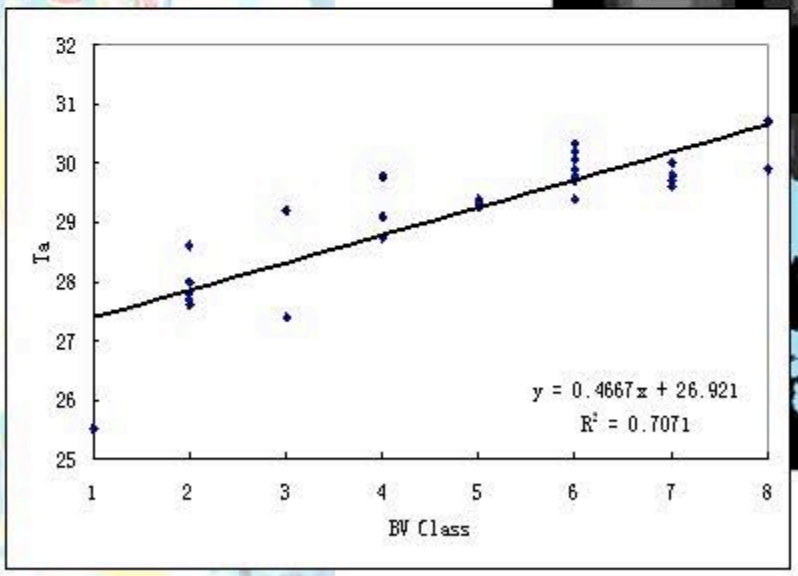


VRi (Wind Tunnel Study) vs. VRi (Field Measurement Study)

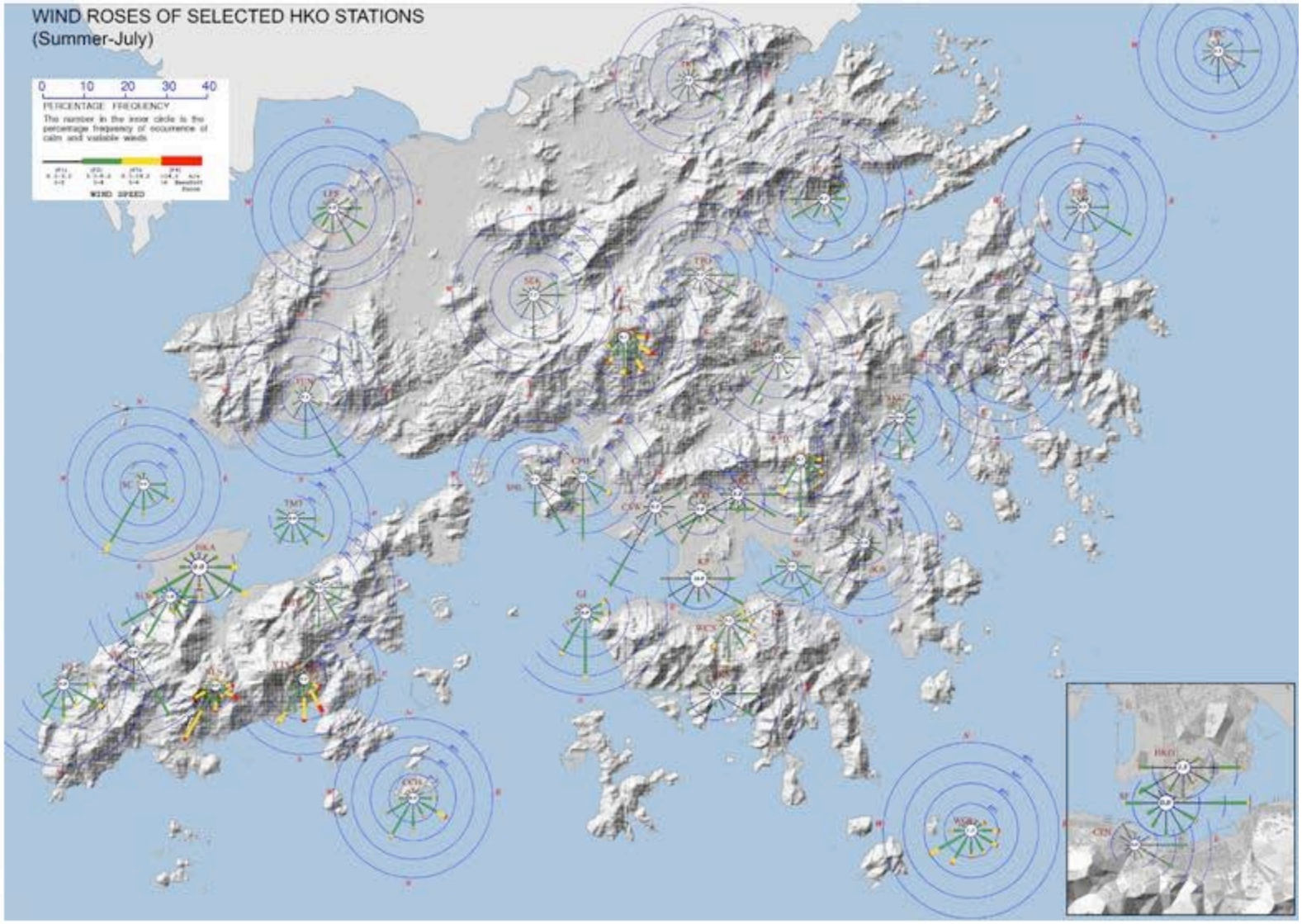
Calibration and validation III



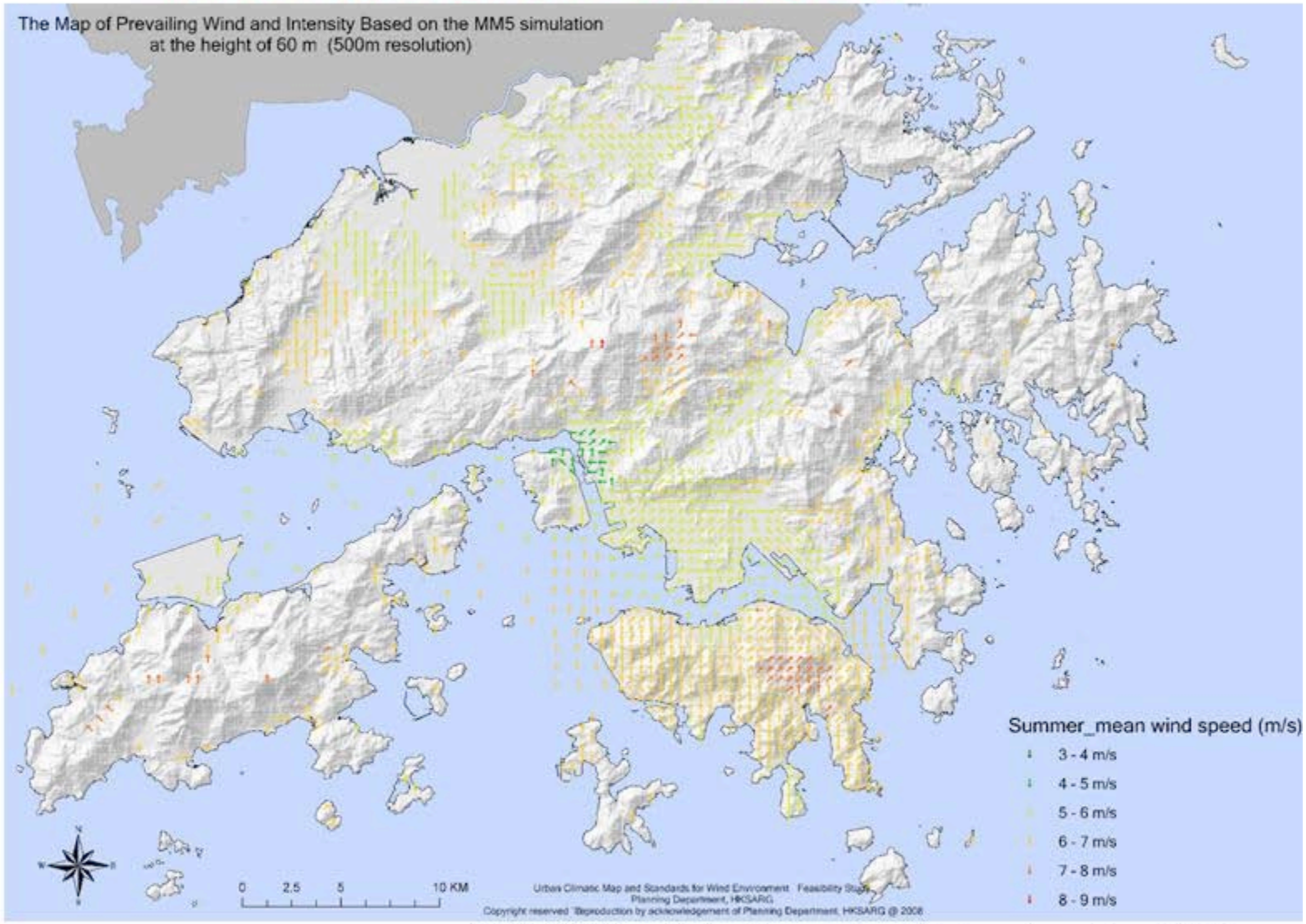




Wind information - observed



Wind information – simulated



MM5 / CALMET model simulation, courtesy of Professor Jimmy Fung, HKUST

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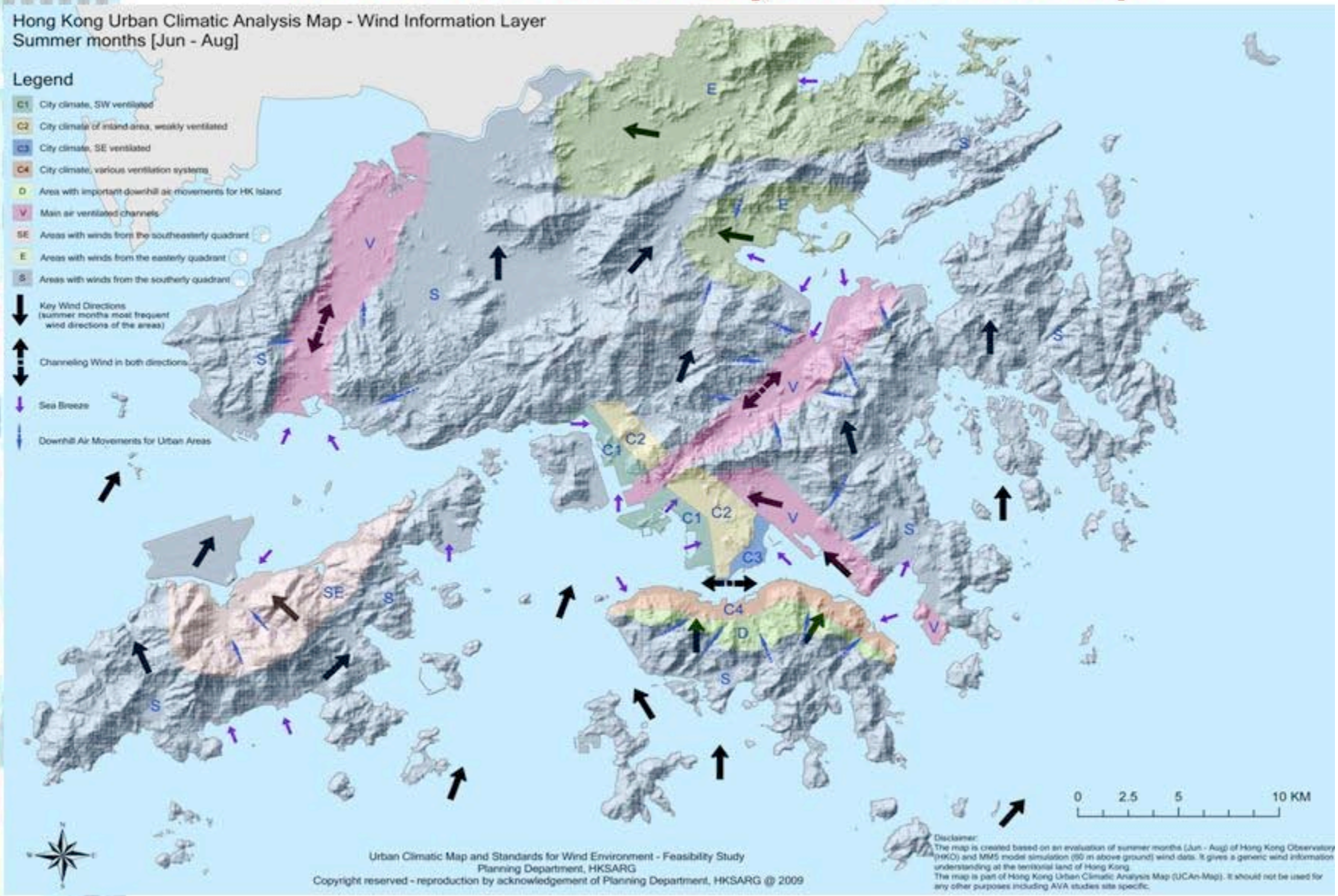
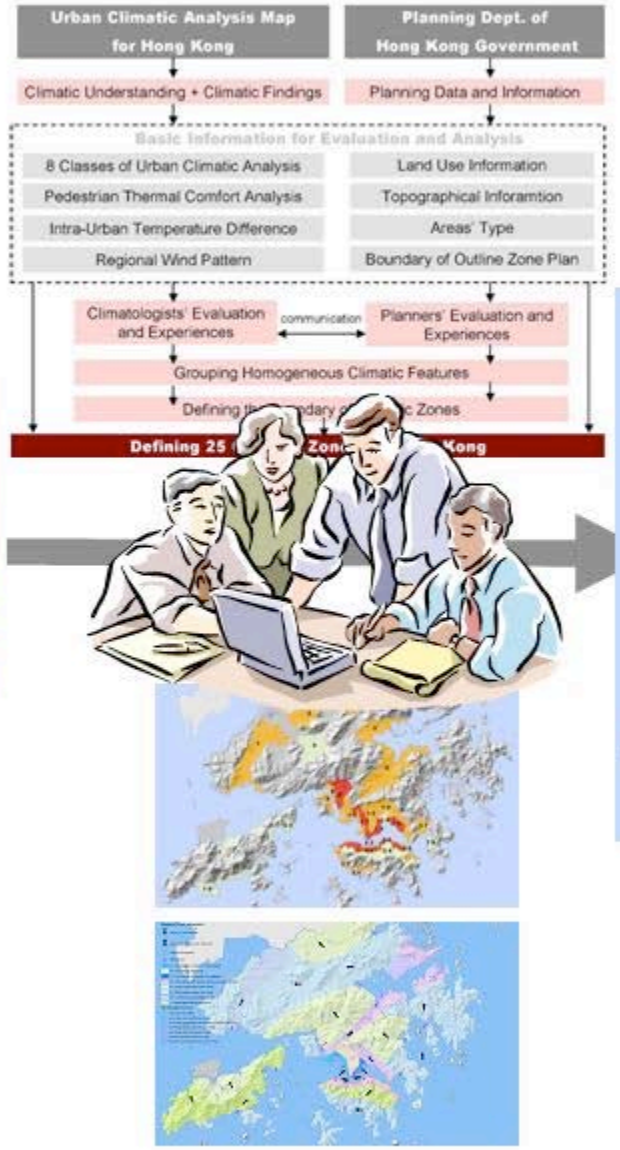
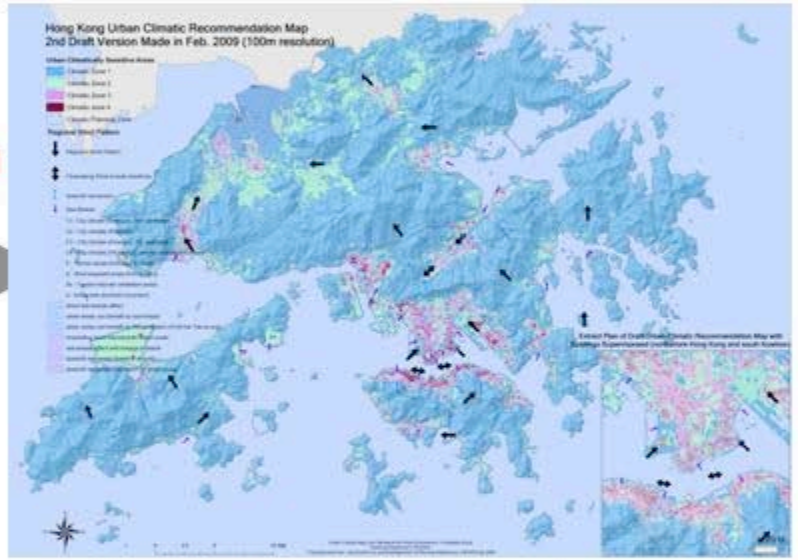
Wind information Layer of HK UCMap



Hong Kong Planning Recommendation Map





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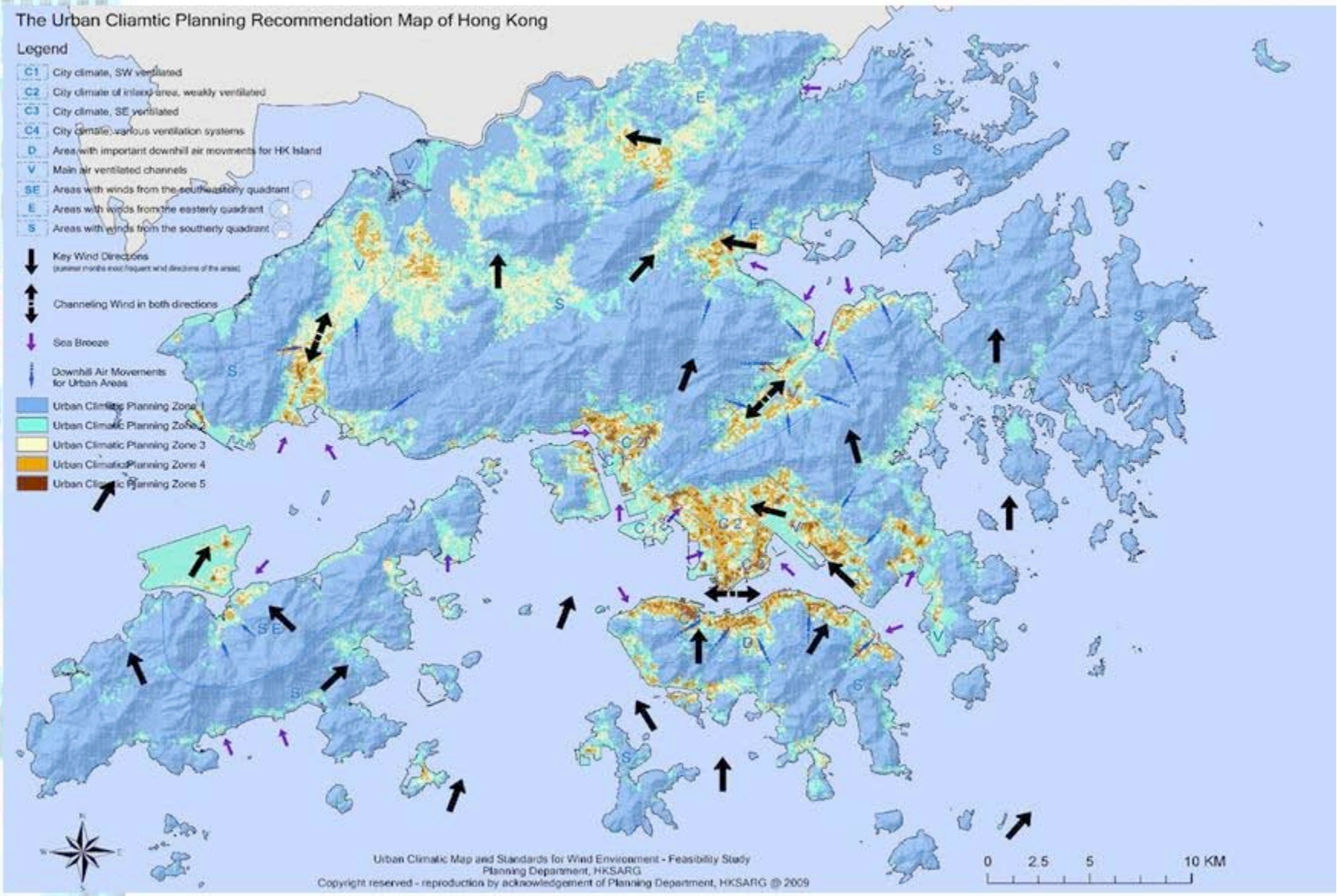
Hong Kong Planning Recommendation Map



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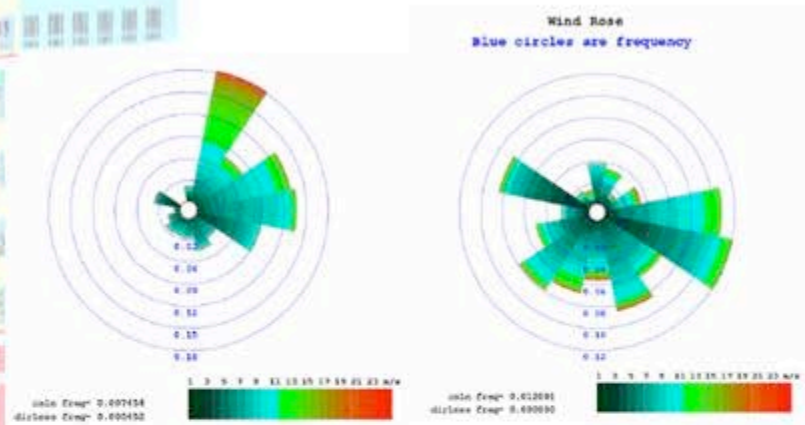
Planning Recommendations

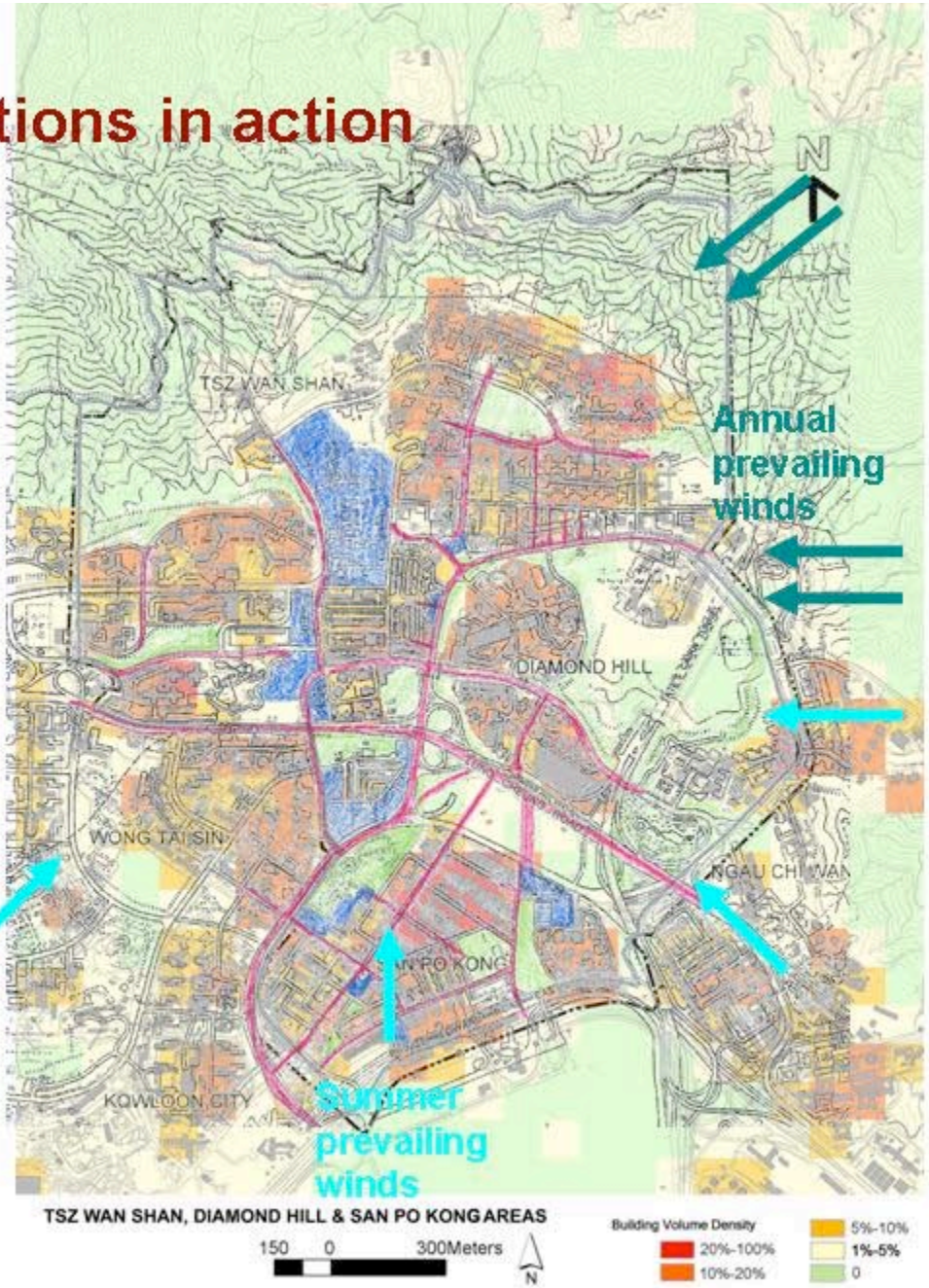
	Urban Climatic Analysis Description	Urban Climatic Classes	Impact on Thermal Comfort	Urban Climatic Planning Zone	Planning Action		General Description on Planning Recommendations
1	These areas are situated on the higher altitudes of mountains and steep vegetated slopes. Adiabatic cooling and trans-evaporative cooling are prevalent to bring about good dynamic potentials and moderately negative thermal load. As a result, the temperature is usually cooler. These areas can be sources of cooler, fresher and beneficial downhill air movement to nearby urban areas.	Moderately negative Thermal Load and Good Dynamic Potentials	Moderate	Urban climatically valuable area	Preserve	1	1 Preserve 2 These zones are extensively covered with natural vegetation, at higher altitude and with few obstructions to wind. Their can provide a cooler and more conducive thermal comfort environment. Their cool air production capability can also be beneficial to nearby urban areas. 3 Natural areas especially cold air production and drainage areas beneficial to other areas (e.g. vegetated hill slopes adjacent to urban areas) should be preserved. No sealing (paving) or development should be allowed. 4 Minor but essential development may be possible in areas other than in natural areas identified in 3 above. Careful planning and design is necessary to minimise disruption. 5 Major but absolutely essential and necessary development (e.g. new town), other than in natural areas identified in 3 above, may be exceptionally considered. Very careful planning and design is necessary to minimise disruption. Breezeways and air paths must be carefully designed. Street grids and building disposition must respect prevailing wind directions. Building Volume and Ground coverage must be kept low. Maximise greenery and open spaces and minimise sealing must be practised.
2	These areas are extensively covered by natural vegetation, greenery, and natural coastal areas including the hilly slopes. Trans-evaporative cooling is prevalent to bring about good dynamic potentials and slightly negative thermal load. As a result, the temperature is usually cooler. These areas can be sources of cooler, fresher and beneficial downhill air movement to nearby urban areas.	Slightly negative Thermal Load and Good Dynamic Potentials	Slight				
3	These areas usually consist of more spaced out developments with smaller ground coverage and more open space very near the sea. As a result, the temperature is neutral.	Low Thermal Load and Good Dynamic Potentials	- Neutral	Slightly urban climatically sensitive area	Preserve and enhance	2	1 Preserve and enhance 2 These zones are currently urban climatically "neutral" in terms of urban thermal comfort. It is important to maintain their urban climatic characteristics. Desirable features like areas with lower building volume, open spaces and so on should be preserved. 3 Further development is possible. 4 Existing air paths must be identified and respected. The prevailing wind directions and air mass movement must be considered when buildings are positioned. 5 Higher Building Volume is permissible should 4 above is respected. 6 Consider reducing ground coverage to improve ground level air volume; 7 consider greening to the open spaces.
4	These areas usually consist of low to medium building volumes in a developed yet more open setting, e.g. in the sloping areas with a fair amount of open space between buildings. As a result, the temperature is slightly warmer.	Some Thermal Load and Some Dynamic Potentials	Slight				
5	These areas usually consist of medium building volumes situated in low-lying areas further inland from the sea or in areas fairly sheltered by natural topography. As a result, the temperature is moderately warmer.	Moderate Thermal Load and Some Dynamic Potentials	Moderate	Moderate Urban climatically sensitive area	Some action encouraged	3	1 Some action encouraged 2 These zones are currently urban climatically "moderate in terms of urban thermal comfort. Some impact on thermal comfort is expected. As such, it is encouraged to consider installing some mitigation measures. 3 Further development is possible and should be carried out with care. 4 Existing air paths must be identified, respected and enhanced. The prevailing wind directions and air mass movement must be considered when buildings are positioned. 5 Higher Building Volume is permissible should 4 above is respected, and it is necessary to balance it with a reduction of ground coverage to improve ground level air volume; 6 Greening to the open spaces and streets is highly recommended
6	These areas usually consist of medium to high building volumes located in low-lying development areas with relatively less urban greenery. As a result, the temperature is moderately hotter.	Moderately High Thermal Load and Low Dynamic Potentials	Moderately strong	High urban climatically sensitive area	Action desirable and recommended	4	1 Action desirable and recommended 2 These zones are already densely built. Thermal Load is high and Dynamic Potential is low. Some strong impact on thermal comfort is expected. 3 Further development is possible and should be carried out with care. A balance consideration of adding Building Volume and reducing Ground Coverage must be considered so that at least a "no worse than existing" scenario could result. 4 Existing air paths must be identified, respected, enhanced and widened. The prevailing wind directions and air mass movement must be considered when buildings are positioned. 5 Greening to the open spaces and streets is essential. 6 Addition greenery and tree planting on streets in these zones is essential and is strongly recommended. Intensify greening in O and GIC zones are also recommended.
7	These areas usually consist of high building volumes located in low-lying well-developed areas with little open space. As a result, the temperature is generally hotter in these areas.	High Thermal Load and Low Dynamic Potentials	Strong				
8	These areas usually consist of very high and compact building volumes with very limited open space and permeability due to shielding by buildings on many sides. Full and large ground coverage is prevalent and air paths are restricted from the nearby sea or hills. As a result, the temperature is very much hotter in these areas.	Very High Thermal Load and Low Dynamic Potentials	Very strong	Very highly urban climatically sensitive area	Mitigation action necessary	5	1 Mitigation action necessary 2 These zones are already very densely built. Thermal Load is very high and Dynamic Potential is low. Very strong impact on thermal comfort is expected. A high frequency of occurrence of thermal stress is also anticipated. 3 No further adding of Building Volume and Ground Coverage should be allowed. 4 Existing air paths must be identified, respected, enhanced and widened. New air paths may need to be created. The prevailing wind directions and air mass movement must be considered when buildings are re-developed and re-positioned "to improve" the existing situation. Strategic mitigation measures (air paths, open spaces, urban greenery, street widening, building set back, and so on) must be considered "to improve" the existing situation. 5 A strategy to utilise all GIC sites to relief the existing condition is recommended. No further tall structure is encouraged on all these GIC sites. Intensify greening is recommended. 6 Addition greenery and tree planting on streets in these zones is essential and is essential recommended. Intensify greening in O zones is strongly recommended.

Recommendations in action



RECOMMEN DATIONS:

- Building Density
- Building Ground Coverage
- Building Heights
- Greenery
- Topography
- Air paths



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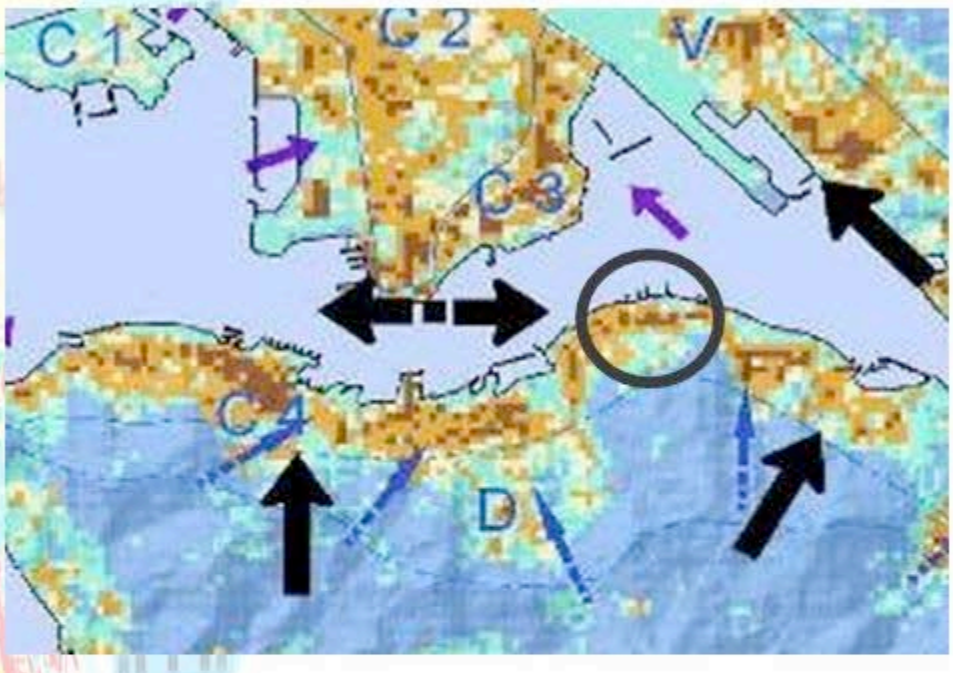
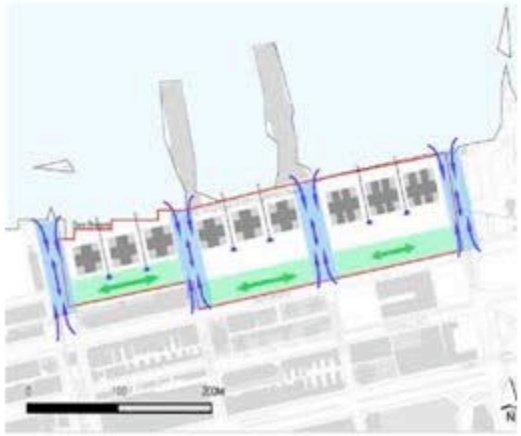
Recommendations in action

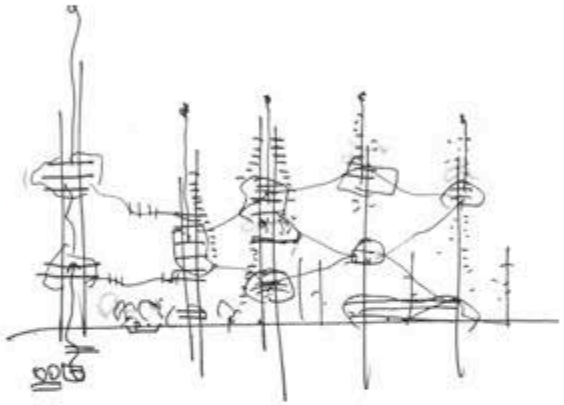




Urban Climatic Mapping in Hong Kong

Towards mitigating urban heat islands in sub-tropical cities

Thanks…



Edward Ng and Chao Ren,*
School of Architecture, Chinese University of Hong Kong

Lutz Katzschner,
Department of Architecture, Kassel University

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